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ENGINEERING. EDITED BY G. MONCUR, B.Sc.
M.I.C.E. M.Amer.Soc.C.E. *Professor of Civil Engineering
in the Royal Technical College, Glasgow*

MODERN SANITARY ENGINEERING

PART II

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SANITARY ENGINEERING

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SEWERAGE

BY

GILBERT THOMSON, M.A. F.R.S.E. M.Inst.C.E.

LECTURER ON SANITARY ENGINEERING IN THE ROYAL TECHNICAL COLLEGE, GLASGOW

PREFACE

THE collection of sewage matters by House Drainage, which was dealt with in Part I, is naturally followed by the conveyance of these matters to the place of ultimate disposal. This is the object of Sewerage, which is considered in this volume.

Sewerage has not suffered from the neglect of its scientific problems to anything like the same extent as House Drainage. The older generation of engineers could refer to the important treatises by Baldwin Latham and Bailey Denton, which are of substantial value even now ; and numerous books and papers have dealt either with the general subject or with some special phase. While marked progress has been made in the design and construction of sewers, the older practice has not become hopelessly obsolete as in the case of House Drainage. The following pages therefore contain frequent references to inventors and investigators, both early and recent, and the Author has endeavoured to acknowledge fully the assistance he has received from work already published. His special thanks are due to those who have given him permission to use copyright matter, and he trusts that any inadvertent overlook in this connection will be pardoned.

His aim in this volume has been to produce a book which would be useful to engineering students, by directing their attention to the constant scientific considerations which control the practical work of the engineer, and which at the same time might be of service to the engineer engaged in practical work by bringing these considerations into convenient form for reference. Special attention has been given to those parts which involve the less

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obvious applications of scientific principles, such as sea outfalls, inverted syphons, and the like ; and illustrations from practical work have been freely used.

The material was prepared several years ago, but publication was delayed by the War. So far as possible, the text has been revised in the light of changed conditions.

G. T.

Glasgow,
        June, 1920.

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MODERN
SANITARY ENGINEERING

PART II.—SEWERAGE

CHAPTER I

THE GENERAL PRINCIPLES OF SEWERAGE DESIGN

Duty of Local Authority.—The responsibility of the individual householder ends when the liquid refuse of his house has been collected by his drainage system and delivered into a public sewer. The further responsibility rests on the Local Authority, whose duty it is to convey the sewage to a place of disposal, and there deal with it so as to produce a harmless effluent.

Powers of Local Authority.—In the case of a scheme involving large outlay it is often convenient to obtain special powers by a private Act of Parliament. The clauses of the Act are framed with reference to the individual case but must be consistent with the general law. The cost of a private Act is substantial in any case, and may be greatly increased if the scheme is seriously opposed.

For smaller schemes the necessary powers can be obtained under the general statutes by giving the required notices. Any person who objects has the opportunity of appearing before the proper tribunal, and when the objections (if any) have been disposed of (which may sometimes involve alterations on the scheme) the Local Authority can proceed as freely as under a private Act.

Purposes for which Powers are Needed.—These purposes are twofold :—

(a) The imposition of rates.

(b) The acquisition of land, servitudes, wayleaves, etc.

(a) **The Imposition of Rates.**—The cost of the works is usually met by a loan, which is to be repaid within a certain limited period, fixed as a rule by the Ministry of Health. Thirty years is a common time for sewerage works, but the cost of land may be spread over a longer time, and on the other hand any structural work or machinery which is not likely to have such a long life should be paid for earlier. Reinforced concrete, for example, has been regarded officially with some suspicion.

It is thus necessary every year to raise by rating enough money to pay the interest on the loan and to pay back the proper proportion of the principal. The most convenient arrangement is to pay a fixed sum per annum, this sum covering both interest and repayment of capital, and remaining the same throughout the estimated life of the work. If the work has still a substantial value when the fixed period has elapsed, the ratepayers of that day reap the advantage at the expense of their predecessors. The engineer is usually called on to estimate the annual expenditure, and the Local Authority judges the feasibility of the scheme by comparing this with the rateable value of the district concerned. The annual expenditure includes, in addition to interest and repayment of capital, the cost of repairs and management, rates and taxes, and any incidental expenses.

There may be a choice of methods of procedure, and these may affect the imposition of the rate between owner and occupier, but this is a matter for the legal adviser of the Local Authority.

(b) **The Acquisition of Land, etc.**—When land is needed for permanent occupation, to the exclusion of any other use—as in the case of sewage disposal works—it is customary to buy it outright. If, on the other hand, it is required for a temporary purpose—such as the construction of an underground sewer—

it is customary to acquire only a " servitude," " easement," or " wayleave." In the latter case a payment (in one sum or annually recurring) is made to the owner, usually based on the linear measurement of the sewer and the number of manholes ; a distinction being drawn between manholes which come to the surface and so interfere with cultivation, and those which are stopped and covered more than " plough-depth " below the surface.

In addition to the ownership claims for the land actually taken or used, there may be claims on the part of the occupier for surface damage, hindrance to cultivation, and loss of value of crop, work, manure, etc., as well as for the loss of the ground ; and on the part of the owner for " severance." The agricultural claims may be very substantial, and may extend over a considerable number of years. While these are not really engineering questions, they all come under the notice of the engineer, who may be called on to report on claims, and in planning the work he should endeavour to give as little ground for these as possible.

Local Authorities have ample powers for the construction of all duly sanctioned sewerage undertakings, and for the compulsory acquisition of land and wayleaves ; but often a great saving of time at least, and possibly also of cost, can be effected if these are secured by friendly arrangement with the proprietors and occupiers concerned. The engineer should make himself familiar with the details of ownership and occupancy, and should see well in advance when any lands are to be touched. If compulsory powers are to be used, due notice must be given, while if access is to be had without the exercise of such powers, it is well to make sure of it in good time.

Planning a Sewerage System.—Although the conveyance and disposal of sewage are treated separately, and although this volume deals specifically with the former, it must not be forgotten that they are really parts of the one problem. The first step in designing a system of sewers is to determine the place or places to which the sewage is to be conveyed.

The final discharge is (a) into the sea, with or without purifica-

tion, or (*b*) into a stream after purification. The preliminary information required with respect to any drainage area is :—

1. The position and level of the point or points of discharge.

2. The position and level of the lowest places that are to be drained.

3. Details as to the possible routes.

Maps.—In the British Islands the Ordnance Survey maps are the basis of all surveying operations for drainage purposes. The " twenty-five inch " sheets are most generally useful. In large towns the five-foot or ten-foot scale is available, while for preliminary investigations over an extended area the six-inch sheets are convenient. For still more general purposes over a very wide area, such as the whole watershed of a river, the one-inch map is useful as giving a comprehensive view. On these maps an actual distance of a mile is represented by distances on the map of " 25 inches " (strictly speaking 25·344 inches) ; five or ten feet ; six inches ; and one inch respectively. The contour lines, or lines of equal elevation, which are drawn on the six-inch and one-inch maps, give very readily a general idea of the shape of the land, but the vertical spacing is much too wide for any detail work. The larger scale maps are more useful for all subsequent purposes, and the former are only used for preliminary investigation. The twenty-five inch maps have a number of " spot " levels marked, and while these are very useful, the information thus given has to be supplemented not only by general inspection, but by levelling operations. These operations are based on one or more of the Ordnance Bench Marks which are cut on buildings, walls, etc., and which are indicated on the map as " ⅄ B.M." with a figure indicating the height above Ordnance datum. In ordinary circumstances these marks are very reliable, but in mining districts the subsidence of the surface may cause great irregularity. The marks may have sunk without any approach to uniformity, and in such a district as a rule it is necessary to select one as a reference point and ignore the others. Of course it is further necessary to remember that in some cases the subsidence may not yet be complete, and that allowance for the future must be made in planning the scheme.

"OUTFALL" AND "INTERCEPTING" SEWERS

Valley lines.—The natural course for a main outfall sewer is alongside a stream. It often happens, however, that a district includes ground which drains naturally toward several streams, and although these unite further down, it may be necessary that the disposal works should be situated at some place above their junction. This calls for an intercepting sewer across the natural routes so as to collect the discharge from several such routes into one. It may be that the course of a stream is so circuitous that the sewer must be laid on a more direct line. A sewer which follows a single valley line will need less cutting than one which crosses from valley to valley, but such a crossing is frequently inevitable (see Chapter II).

Shore Lines.—A special class of intercepting sewer is that which runs along the shore. Every seaside town will naturally reach a condition calling for such a sewer. In its early stages the sewage difficulty is met by constructing a number of sewers or drains, each discharging on the foreshore, often far above low-water mark; but sooner or later this becomes intolerable, and an intercepting sewer running along the front is needed. If the tributary sewers or drains are at a low level, and if the intercepting sewer has to be carried to any great distance, some method of mechanical raising is inevitable. When a sewer follows the course of a fast-falling stream it is easy to gain elevation—relative to the stream—by going further at a flat gradient: this is quite impossible when the discharge is into the sea. It is a question therefore which admits of a fairly simple answer, whether in any given place it is or is not practicable to deliver the sewage into the sea at a sufficient distance from the town by gravitation. The resulting problems, whatever the answer may be, are by no means so simply solved, and are discussed in Chapter IX.

Sewer Routes.—Assuming that the point of delivery has been determined, the routes for the main and subsidiary sewers must be selected subject to the following considerations :—

1. They must afford gradients which will produce a self-

cleansing velocity, having in view the size of the sewer and the amount of liquid to be conveyed.

2. They must suit the present conditions and the probable future development of the place.

3. The depth of cutting and consequent cost must be as small as is consistent with the above conditions.

4. The routes must as far as possible avoid ground where there are any special difficulties—either physical, such as the proximity of heavy buildings or unstable ground : or financial, such as ground for which heavy wayleave payments will be demanded.

Proportion.—Sewerage operations are of very varying magnitude, and this affects all the above requirements. Gradients, depths, and special costs which would be quite impossible in a small scheme, may be unimportant incidents in a large one.

Starting-points.—A system of sewerage collects sewage from all parts of a specified area, and delivers it at a specified point. The area for which sewerage is to be provided, and the place at which the sewage is to be delivered, are therefore the main factors which determine the design of the system.

These factors may both be at first indeterminate. It may happen that the area is fixed, as in the case of a town or of a drainage district already formed : but on the other hand it may be that the delimitation of the district depends on what is found suitable for inclusion in the scheme. It may be a further question whether a given area should be drained to a single outfall or to several at different places : and conversely, whether it would be well for two adjoining towns or districts to unite in a common outfall system.

In the same way, there may be several sites more or less suitable for disposal works, and it is the business of the engineer to see which of these is best, taking into account both the construction of the necessary sewers and the construction and subsequent operation of the works themselves.

It is only after careful investigation that our starting-points can be fixed, and while they are starting-points as regards the

detailed design, they are really the conclusions reached after a great deal of preliminary work.

District to be Sewered.—If the engineer is consulted while the area to be sewered is still uncertain, he will propose boundaries suitable for his intended scheme—bearing in mind that the parts left out may in their turn require attention by the formation of a future district or by an extension of that first proposed. In what follows it will be assumed that the engineer has either definite or approximate boundaries indicated to him. If the boundaries are only approximate, the considerations to be discussed will assist him in proposing definite boundaries, this being usually done in collaboration with the executive officials of the Local Authority.

Site for Disposal Works.—For small populations where one man could look after the works if they were all in one place, it is worth while to incur considerable capital outlay to effect concentration to one outfall. Otherwise it means that (1) one man has to divide his attention among several scattered works, or (2) several men are employed as part-timers. Neither of these arrangements tends to efficiency and economy. When the works are to be on a large scale, requiring for their management a considerable staff of men, it is possible that economy of construction may properly lead to several works being constructed, each to deal with the sewage of one part. For the same population it may be said generally that concentration to one site means greater capital cost for sewers and less for purification works ; and that the economy in working with one outfall is more pronounced the smaller the total size of the works.

It is always desirable that sewage works should be at a reasonable distance from dwellings, and from any place where amenity is of importance. The material treated, and the associations, are sufficiently unpleasant to make this desirable, however inoffensive the works in themselves may be, and small works are not necessarily more free from unpleasantness than large ones.

It will be assumed that all the sewage is to be taken to one

place of disposal. If there are more, then each is designed as a separate scheme, and the same principles apply to each.

Possibility of a Gravitation Scheme.—The first point to be determined is whether a gravitation scheme is practicable, or whether some means of raising the sewage will be necessary.

The former of course is obviously very desirable, and warrants a substantial increase in the cost of sewer construction. It saves not only the capital cost of pumping plant, but the constant cost of running and maintaining the plant.

The possibility of a purely gravitation scheme depends usually on the fall of the stream into which the effluent is to be discharged as compared with the fall required for the sewer. In most towns and districts it happens that some of the houses are built near the level of a stream, so near it sometimes that there is only fall enough to discharge direct into it, while every system of purification requires some fall for its working. The problem which faces the engineer is to get the sewage to a place where it is sufficiently high above the stream to give height for the required works. If a satisfactory sewer can be laid with a gradient less than that of the stream, then it is physically possible, by going sufficiently far down stream, to reach the necessary relative elevation : the cost decides whether it is practicable. If the stream is sluggish and flat, then the sewer will probably require at least as much fall as the stream, and nothing can be gained by going down stream, unless the latter has a tortuous course, in which case a sewer with a shorter route may gain fall.

This is illustrated in Fig. 1. The town represented diagrammatically at A might conveniently have sewage works at B, but the river level is too high to give an outlet. If the necessary gradient of the outfall sewer is less than that of the river, it may be possible by carrying the sewer to C to reach a place where the height of the sewer above the river is sufficient to give fall for the filters. But suppose that this is not the case, a gravitation scheme might still be possible if the course of the river were as shown, by carrying the outfall sewer to D instead of C. The sewer is not any longer, and thus no more fall is needed—that is, the sewage can be delivered at D as high as at C—but the distance

measured along the river is almost doubled, and the river level
at D will be lower than at C, thus giving a greater available fall.
Such an expedient is often practicable, but it will be noted that
it involves two difficulties (1) a river crossing, and (2) crossing
a neck of land which may be high and thus involve deep cutting
or tunnelling. The local considerations will determine its feasi-
bility. The river crossing must either be under the river, which
involves the use of an inverted syphon with its attendant troubles,
or over the river, in which case it must be sufficiently high to be
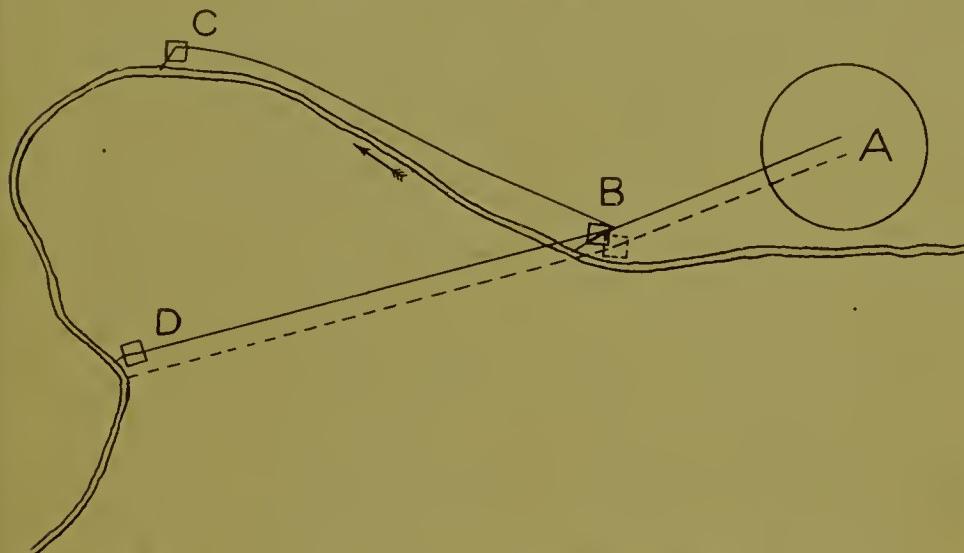
Fig. 1.—A Choice of Outfall Routes.

clear of floods—both for its own safety and to avoid any damage
due to the obstruction.

In this connection it may be noted that in such a case it might
be quite possible to construct the works at B, but to carry the
outfall drain to D as indicated by the dotted lines. This might
admit of the crossing under the river without using an inverted
syphon, the natural run of the sewer being sufficiently low : and
might also permit the use of a flatter gradient on the outfall
from B to D on account of the reduced quantity of matter
carried in suspension. On the other hand it implies that the
works are constructed at a level which is low in relation to the
adjoining river, and also that the outfall sewer from B to D is a
deep one. When works are constructed at a low level alongside

a stream the trouble from water (either percolating or flowing over the banks) is apt to be serious : and the addition of six or eight feet to the depth of the sewer between B and D may add greatly to its cost. As a rule, therefore, it is no advantage to have a long outfall drain beyond the purification works, but special local conditions may render that arrangement advisable.

Raising Sewage.—If a purely gravitation scheme is not practicable, the next inquiry is whether this is due to the general conditions of the district, or to those of a few small parts. If only small areas lie too low it may be inquired (1) whether these might properly be omitted from the general scheme and dealt with exceptionally, or (2) whether some mechanical means (see Chapter XIV) should be adopted for raising the sewage from these small areas to a main sewer at a higher level. The first course might be permissible for example where only a few detached houses here and there stood on low ground near a stream of moderate size. A fairly primitive means of purification—even a cesspool—might be tolerated for the sewage from a few houses in such circumstances.

Doubtful Cases.—There are many cases where a gravitation scheme is obviously practicable, and there are many where it is as obviously impracticable. But there are others on the boundary line, where a gravitation scheme may be possible by careful design, although at first sight it may appear to be impracticable. In any case of apparent impracticability where the margin is a narrow one, every possible way of avoiding a general pumping scheme should be considered before finally deciding that such a scheme is inevitable. In the author's experience the scale has been turned by re-arranging the private drainage of a few low-lying houses.

Purification Methods as Affecting Sewerage Design.—Purification works of the usual type include tanks and filters, and in the design of these there is a wide range as regards the fall required. Ten or twelve feet is common, but this may be substantially reduced or considerably exceeded. When any method

of forced aeration is used, the sewage may be raised in the process and this may sometimes tell strongly in favour of such methods.

Size and Gradient of Sewers.—The size of a sewer has an important bearing on the gradient at which it may properly be constructed (see Chapter IV). The importance of this in the preliminary investigation is that as a large sewer may be properly constructed at a gradient which would be hopelessly flat for a small sewer, it is desirable (in every case when it is important to save fall) to concentrate the flow as soon as possible.

For example, suppose there is a town or district A (Fig. 2) with a stream running through it, the houses on both sides coming close down to the stream. Half a mile below the town there is a
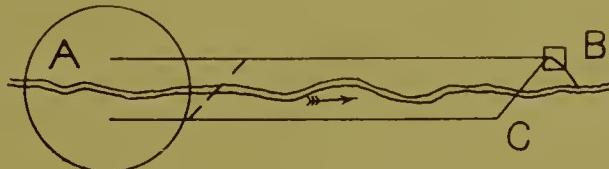
FIG. 2.—Concentration of Flow.

suitable place B for purification works, but the fall is very small. A 15-inch pipe down each side of the river, from A to B and C respectively, one of them crossing close to the works, might appear suitable ; but if the crossing were made close to the town, as shown by the dotted line, and one pipe only of, say, 21 inches were used, it might be laid at a gradient considerably flatter, and valuable fall would thereby be saved. Such concentration might make all the difference between the possibility and impossibility of a gravitation scheme, and even if it involved an extra crossing of the river it might be well worth while. The one large pipe would cost less than two smaller ones, but this, however important in itself, is by comparison of small consequence.

Selection of Routes. Depth and " Cover."—For all sewers, but especially for the main outfall sewer (which in most cases has to be laid with a flat gradient), it is important to select a route which avoids excessive depth, and at the same time provides sufficient " cover." Under streets and roads it is desirable that

no part of the sewer should be nearer the surface than three feet :
in agricultural ground eighteen inches may be enough. In the
one case the object is to avoid injury to the sewer from the weight
of traffic, in the other it is to avoid interference with agricultural
operations. Subject to these limitations, the less depth (beyond
that necessary to provide for all present or future drains) the
better : the depth of cutting not only increases the certain cost,
but it adds to the chance of unknown cost due to troublesome
material.

But however objectionable deep cutting may be, banking
is often still more serious. When a sewer is constructed in cutting
of sufficient depth, it is finally out of the way ; but when banking
is needed for its support or protection, there is a permanent
interference with the ground surface. In some cases this may be
an absolute bar to the proposed route, and in every case it adds
to the difficulties and complications. The matter is considered
in more detail on p. 66, but is mentioned here to point out that
banking should be avoided if possible in the selection of routes.
It is most troublesome in the case of flat sewers : where ample
fall is available there is little difficulty, as it is then usually easy
to improve the route by making it longer.

Gradient.—One of the most difficult points to decide is what is
the flattest permissible gradient. It is easy to calculate the
theoretical velocity of flow for a sewer of a given section and with
a given gradient, assuming it to be running " full," " half-full,"
or at any given proportion of depth. It is easy also to refer to
tables and to see that the flow in a sewer of given size should
have a certain minimum velocity. But it very often happens
that for some portion of the work there would be a great saving
in cost—representing perhaps even the difference between the
possibility or impossibility of a scheme otherwise very desirable—
by a departure from the ordinary rules. In many cases such a
departure is justifiable. In other cases it would be quite improper,
and even a sewer laid in conformity with ordinary rules might
prove unsatisfactory. The subject is discussed later in detail
(Chapter IV), but the adoption of certain gradients (of course
within comparatively small limits) can neither be finally justified

nor condemned by calculations. An engineer engaged on such a design depends largely on experience and on his knowledge of the local conditions to supplement the results of calculation.

Public *v*. Private Ground.—It is sometimes inevitable, especially in country districts, that sewers should be laid through private ground. The obvious difficulty which this involves is met so far as legal rights are concerned by the statutory powers given to Local Authorites. These powers are very wide. If it is certified by the responsible engineer that passage through certain ground is " necessary," then a wayleave can be demanded : and " necessary " has been interpreted in a fairly broad sense. It does not mean that no other route is possible, but merely that the proposed route is reasonably necessary.

Of course any surface damage must be paid for, and the line must be laid out so as to avoid any needless damage. In ground likely to be used for building it is desirable to arrange with the proprietors that the proposed sewers should run on the line of proposed streets ; and it is always well to submit the proposals, so far as practicable, to those interested in the ground before any formal steps are taken. It is much easier and pleasanter to make modifications as the result of friendly conference than as the result of an unsuccessful application for compulsory powers.

Where there is a choice between going through private ground and keeping to public streets and roads, it is worth while to sacrifice a good deal for the sake of the latter. It is bad policy to lay a public sewer through garden ground behind houses, merely for the sake of shallower cutting or shorter connections. Access for inspection and repair is of considerable value, and can best be secured by keeping to roads, streets, or lanes whenever possible. In arranging the drainage of a " housing scheme " however, it is almost essential to collect the sewage by means of " sewers " or " combined drains " passing through private ground and each serving a number of houses. (See Chapter XVIII.)

Railways, Canals, etc.—Where such lines of communication cross the intended line of sewer, the engineer should put himself

in communication with the engineer in charge of these under-
takings, and consult him as to how the necessary crossing can
be arranged with least difficulty. Railway companies have
special powers, and can if they choose cause very considerable
difficulty. Here again it is better that any objections should be
known and met in advance rather than that they should come
up formally at a time when they may cause difficulty and delay.

Official Inquiries.—In England, public works such as
sewerage (except when special Parliamentary powers are
obtained) require the approval of the Ministry of Health, and
this is given or withheld as the result of a formal inquiry. An
Engineer Inspector visits the place and conducts the inquiry,
at which evidence may be led by the Local Authority on the one
hand and by any objectors on the other, and which includes not
only engineering but also financial questions. The Ministry
gives its decision on the report of the Inspector.   In Ireland the
procedure is similar.

In Scotland the proceedings are much less formal, and unless
a loan is asked from the Public Works Loan Commissioners the
approval of the Scottish Board of Health is not required. When
the approval is required, the Board is furnished with detailed
plans, specifications and estimates, reports from the local
Medical Officer and Sanitary Inspector, and details as to rating.
Thereafter an Engineer Inspector visits the place and examines
the proposals on the spot, but this is entirely informal.
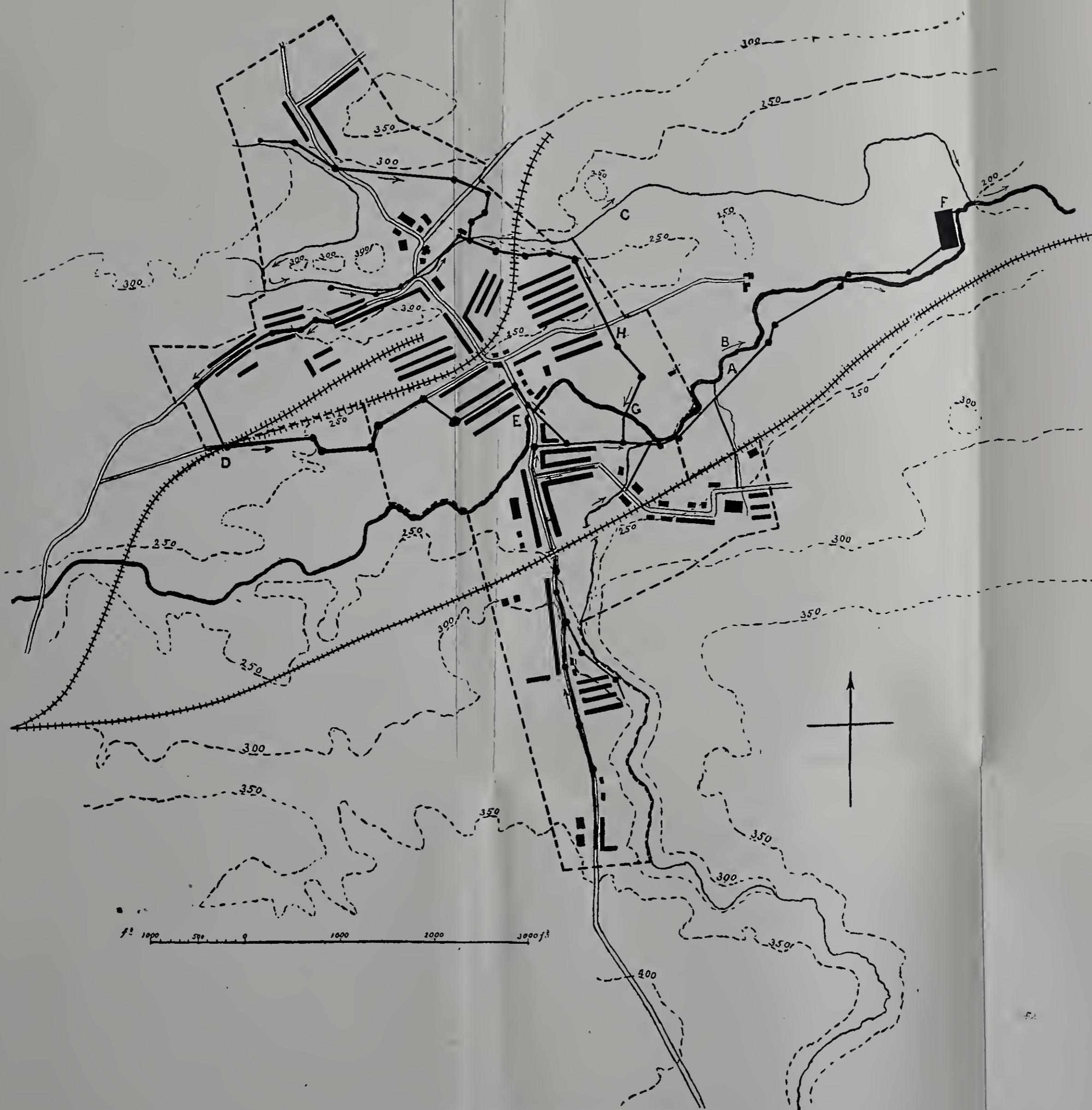
FIG. 3.—The Evolution of a Scheme.

CHAPTER II

THE EVOLUTION OF A SCHEME

MANY of the principles of design will be understood more readily from an actual example than from general statements, and the following has been selected as introducing a fairly large number of problems.

The case is that of a mining community which had grown up rapidly in a few years. The population, when the sewers were designed, was about 6000, with a probability that it might reach 9000 or 10,000. The houses were mostly in groups, each group with a drain to the most convenient water-course, and these drains were utilised as much as possible.

Fig. 3 shows the general features. A lighting district had already been formed, and the same boundaries, not selected with a view to drainage facilities, were adopted for the drainage district.

A study of the map, which shows the drainage district in general outline, with contours at 50 feet intervals, gives the following information :—

The district is divided into two unequal parts by the river.

The river has not a very rapid fall (it was actually about 15 feet from the bridge E in the middle of the district to the point F finally selected for the discharge of effluent, giving about 10 feet per mile), but on either side the ground falls toward the river with fair rapidity.

At the bridge there are houses close to the river on either side, and it might be suspected from the plan (as is the fact) that their drainage level is not much above the flood level of the stream.

While on the south side all the sewers lead to the river within a comparatively short distance of each other, suggesting concen-

tration towards A, there is on the north a much more complicated system :—

There are first the discharges which come direct to the river, and which might apparently be concentrated towards B.

The tributary stream on the north has a tortuous course, suggesting C as a point for concentration, but this leaves the problem of junction with the main system unsolved. Owing to its curious course at the west boundary, leaving and then returning to the populous part, a sewer following the stream would be too long.

Finally, there is a considerable amount of sewage going westward towards D, which cannot be taken directly eastward owing to a considerable hill.

There is thus the obvious suggestion, which was at one time under the consideration of the committee in charge of the District, that the sewage should be led to four different places ; A, B, C, and D, and treated at each of these. This would have been substantially cheaper as regards sewers, but of course more expensive as regards purification works. A serious objection was that no one of the four works (or even A and B combined) would have been big enough to call for the constant employment of a superintendent ; and thus the difficulty of divided employment and responsibility was introduced. On the other hand, one man with occasional assistance could look after everything if it were at one place.

It was found on further investigation that the sewage from the lowest parts could not be delivered at A or B by gravitation with sufficient head above the river to permit of filtration. A pumping scheme was proposed, but the estimated cost of construction and maintenance was prohibitive. At this stage the task of the engineer was to find if possible some means of conveying the sewage to one point and treating it there, with no power other than gravitation.

The points to be determined were :—

(1) Is it practicable to combine the four parts ? and
(2) Is it practicable to convey the sewage by gravitation, from

the lowest parts of the district to any place suitable for disposal works, reaching the site at such a height above the river that the distribution and filtration should also be by gravitation ?

The first involved three questions :—

(*a*) could the river in the neighbourhood of E be crossed ?

(*b*) could a connection be made between the sewer outfall near C, on the tributary stream, and the line of main outfall ?

(*c*) could the discharge toward D be brought round into the main valley ?

With regard to (*a*) it was obviously possible, but as obviously undesirable, to do this by an inverted syphon. Whether a crossing above water could be made low enough to drain the houses and high enough to clear the flood level of the river was a narrow question, and required much careful consideration and the taking of numerous levels. It was decided finally that a crossing from north to south (but not from south to north) was practicable just below the bridge, and as that disposed of the sewage which originated at a low level, it might be taken that all the sewage on the north could be brought to the south. The crossing at G presented no difficulty as it could readily be kept high. This sewer in fact was originally designed to join the other near E, but was altered to meet another point which came up later.

With regard to (*b*) the question was merely depth of cutting. It was impracticable to follow the course of the small stream (and it was important to get this sewage into the main sewer high up, as will be seen), but the cut across southward from near C to H was found to involve no unreasonable amount of deep cutting (a maximum depth of 12 feet, and a total length over 6 feet of 200 yards). This therefore was practicable.

With regard to (*c*) there was no great difficulty, except the financial one that it required a considerable length of " unremunerative " sewer, which was moreover outside the District. The only engineering difficulty was in finding a route free from the necessity of banking, and one part of the road along which the sewer passed had to be slightly raised.

Altogether it appeared to be reasonably practicable to collect everything into one outfall sewer, and to effect this concentration close to the bridge.

This had an important bearing on the other question (2). If the sewage was in sufficient quantity to justify the use of an 18-inch pipe, a gradient would be permissible which would be so much less than that of the river that (added to the saving due to the shorter route) satisfactory filtering arrangements would be just practicable at F, while if any less size of pipe were indicated, the greater fall which would be needed would be practically that of the river, and little would be gained by following it down stream. It was found that when all the sewage was collected into one channel, an 18-inch pipe was a suitable size.

It was therefore evident :—

1. That the sewage must all be collected into one channel as high up as possible. A pipe down each side would not do.

2. That this was possible on the south side, but not on the north.

3. That suitable ground existed on the north but not on the south.

There remained the selection of a suitable line of outfall sewer, and of getting that across from the south to the north. The former was difficult, as the ground consisted in part of high banks close to the river, and in part of fields not much above river level. The latter required a certain amount of banking. The river crossing was easy enough, as the pipe was gradually rising with respect to the river, and a crossing near the works was well above flood level. This, like the other crossing, was effected by means of a steel tube, self-supporting over a span of (in this case) 30 feet. Fig. 4 shows this tube with its supports, and indicates also the adjacent banking.

Mineral Workings.—There was an added difficulty due to mineral workings. These working are gradually coming from east to west, and so any subsidence will affect the east end of the main sewers in the first instance. It was thus essential that any sewer whose gradient was at all flat must run from west to east, otherwise reversal of its gradient might occur. For this

reason the sewer originally projected from H to the corner just north of E was abandoned and the extra river crossing at G was substituted.

Existing Sewers.—The new sewers picked up the various existing sewers, which to avoid complication are not shown on the plan. The plan is to be regarded not as showing anything in exact detail, but as a diagrammatic representation of the requirements to be met and of the means adopted to meet them.

Cost of Works.—In view of what has been said regarding proportion, it may be of interest to add that the total cost of
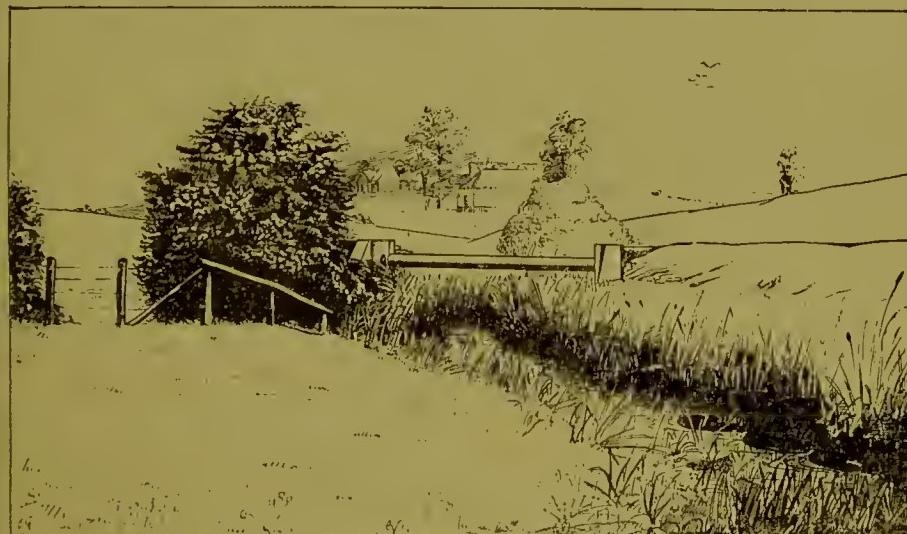
FIG. 4.—Steel Tube across River.

the whole works, including sewerage and sewage disposal works, was about £11,000. Of that total, about £4000 was applicable to the system of sewers. The works were on the point of completion when war broke out, so that the above costs were " pre-war."

Railway Crossings.—There were four crossings, but none involved any difficulty. One was under a bridge which carried the railway over a public road, and where therefore the ownership

of the ground was in public hands. Another involved the passage of a pipe sewer through a culvert under the railway, and it was necessary to satisfy the Company's engineer that no harm was done to the structure of the culvert and that there was no obstruction to the passage of water. The other two involved cutting across the track, but as the line in these cases was a subsidiary one with limited traffic there was no trouble.

CHAPTER III

THE size of sewers is based on the quantity of liquid which they have to convey ; except that in the case of small branches, which may have to convey very little, there is nevertheless a minimum below which it is undesirable to go. This is commonly given as nine inches, but in practice it is not uncommon to find sewers of six inches in diameter.

While sewers must be sufficient for their work, it is undesirable that they should be needlessly big. In that case they not only cost more, but they are less effectively washed out either by natural flow or special flushing, and they hold a larger volume of impure air. When sewers were constructed in the expectation that they would become " sewers of deposit "—to be cleaned by manual labour as a matter of ordinary routine—it was important that they should be big enough for the free passage of the sewer men : but with the modern system of " self-cleansing " sewers this is of little consequence. It is only when the size necessary to carry the sewage approaches that which would admit a man that the latter point would be considered at all : it might then lead to an increased size, but only if a very moderate increase would give the passage.

Minimum Size.—It is found by experience that when sewers (which in small sizes are always round pipes) have a diameter less than about nine inches, the tendency to accidental obstruction increases. In theory anything which is able to pass into the drainage system of a house through the trap of the water closet ought to pass freely through a pipe which is even slightly larger, and as the " throat " of a closet trap is not more than $3\frac{1}{2}$ inches in diameter, it might be assumed that a four-inch sewer

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would be sufficient. This is not found to be the case. The closet outlet is smooth and the plumber's joint causes no obstruction. In the sewer the joint is of a rougher description and is made probably with less skill. Besides, there is at the closet outgo a strong rush of flushing water, as compared with what is in the sewer often a sluggish flow. The result is that such things as paper, rags, etc., pass freely through the one, but catch on rough edges in the other, and a very small obstruction will cause (or at least originate) a stoppage in a four-inch pipe. With a six-inch and still more with a nine-inch pipe there is room for the flow to go on in spite of such an obstruction, which has a great chance of being washed away or even of decaying away. In sewerage systems for villages, especially where the gradients are good, it would frequently be quite reasonable to use sewers of six inches diameter. For all other cases nine inches is the accepted minimum: pipes of seven or eight inches diameter, which might occasionally be useful, are seldom manufactured.

Calculation of Flow.—In deciding what size of sewer is to be used, the volume to be provided for depends on (1) the maximum flow of actual sewage, (2) the provision required for future extension, and (3) the rainfall. Subsoil water may also demand consideration, especially when old sewers are to be coupled up, but new sewers are always designed to exclude it (see p. 81).

Quantity of Actual Sewage.—This is obtained with fair accuracy from the water supply. It is customary to assume that the maximum flow is double the average flow, and where the water supply is normal it would be proper to provide in the sewer a carrying capacity of double the average flow. It is not easy to say what water supply should be regarded as " normal," as ideas differ widely in different districts. In some places 15 gallons per head per day satisfies the demand, in others two or three times that amount might be accounted for by more lavish use. Where the water consumption is low it would be well to consider the possibility of its being increased, and if necessary to make provision for this: while if the quantity is abnormally great it is probable that a good deal of it is due to waste, which is fairly

constant throughout the 24 hours. In that case it would not be necessary to double the average flow, but to double only the "normal" average flow. If, for example, a town comsumed 100 gallons per head per day (unless where the manufacturing demand were great) it might safely be inferred that about half of that quantity was flowing day and night, and the maximum flow would be obtained by doubling the quantity actually used—say at most 50—and adding to that the quantity being wasted—say 150 in all and not 200. In such a case, however, meter tests on the supply should be carried out. Where trade processes require water in large quantity it is of course necessary to add this according to the maximum discharge.

Provision for Future Development.—This is often a very uncertain quantity. The area of unbuilt ground within the district, or within the area to which the sewers may be extended, is used as a basis of calculation ; but a number of more or less conjectural quantities are involved and the result may be very unreliable. An old market town, a rising holiday resort, and a mining village, are among the very divergent kinds of district. and a calculation suited for the one would be hopelessly astray in the case of the others. In a holiday resort it may be necessary to take into account not only the resident visitors but also the "day-trippers." Local information should be obtained as fully as possible, but it needs careful sifting, and the estimates of future growth may be very discordant. Calculation of increase from previous census returns is of little value in those cases where it is most needed.

It happens fortunately that the greatest uncertainty is usually on the fringes of the district, where even the mimimum size is too big for present requirements and gives a substantial margin for increase. In such cases the chief point is to see that the main sewers are of sufficient capacity (see p. 29).

Rain-water—Combined or Separate System.—The "combined" system means that all the rain-water is received into the sewers, although part of it may be subsequently rejected by means of storm overflows. The "separate" system means that there are

two sets of channels, one receiving the actual sewage and the other the rain-water, the two being kept entirely separate.

Limitations of Separate System.—In a large town, it is usually inevitable that all the rain-water should enter the sewers. The street washings can scarcely be discharged untreated into a stream : and besides, the duplication of channels would be troublesome, and mistakes in the way of connecting to the wrong system would be difficult to avoid.

In smaller towns and rural districts it is often possible to keep much of the rain-water which falls on the streets and roads out of the sewers. In sewering such places it is usually found that there are old channels of a kind, which have gradually been converted into sewers : the new system is being laid to supersede these. In place of pulling them out they may be left for their original purpose of carrying off the rain-water, thereby relieving the new system of that part of the work. This is easy so far as the road drainage is concerned.

But the roof and yard or garden space of each house receive rain-water, and if this is all to be kept out of the sewers it is necessary to put in a double drainage system for each house, as well as a double sewerage system in the public streets and roads. If this is done the result is the completely separate system, and the sewers are designed without reference to the rain-fall. But it is not often that this is possible, or even desirable. Each house would then have two sets of drains, and as the pipes between the sanitary fittings and the sewer cannot be less than a minimum size, which minimum (four inches) is in most cases amply large enough to carry rain-water as well as sewage, each of the two sets is big enough to do the work of both. In other words, while the main sewers may be made smaller than they otherwise would be, the adoption of the separate system leaves the branch sewers and the house drains as big as ever, and adds a new set to them. It is therefore in most cases undesirable to carry the separation so far as to require the duplication of house drains, but the rain-water from the front part of the roofs and front gardens or yards may often be made to join the water from the streets and roads in its passage to the rain-water sewers.

Flushing Value of Rainfall.—This cannot be taken as an argument altogether for or against the admission of rain-water to the sewers. In a sewer of given size, which is able to carry a quantity of rain-water in addition to the sewage which joins it, the admission of this rain-water is an advantage, as it means from time to time an increase in the velocity and hence of the scour : but if a sewer has to be increased in size to take the rain-water, the permanent advantage of a good hydraulic mean depth (see Chapter IV) is sacrificed for the sake of the intermittent one. Other things being equal, the less fluctuation of flow the better ; and this is best attained by the exclusion of rain-water. It is often desirable to admit rain-water to the sewers, but this is usually for other reasons than the advantage of flushing.

Allowance for Rain-water.—It is not sufficient to consider the rainfall in relation to the whole of a district : each area must be considered independently. Failure to keep this in view has been responsible for much trouble, and it is probably not unfair to say that the half knowledge contained in the fact that the London main sewers were designed to deal with a quarter of an inch in 24 hours has been responsible for many sewers of insufficient size. The smaller the area under consideration, the greater must be the allowance for rainfall in proportion to that area. The kind of rainfall which gorges a small branch sewer is quite different from that which gorges the main outfall sewer of a large city. The latter is severely taxed by the steady long-continued down-pour which produces a high record of rainfall for 24 hours. The former has to deal with the sudden shower which may only last for a few minutes, but which is much more intense while it does last. An inch of rain in 24 hours is a very heavy fall, and would tax severely many main sewers even if it were evenly distributed, but it would not trouble the smaller branches. On the other hand, a fall of a quarter of an inch in 15 minutes might cause much local trouble without gorging the main sewer. Such a downpour is usually very local, so that many parts of the district would get none : while even if the area affected is extensive its distance from the outfall is various, and the effect there is spread over a much longer time than the actual fall. For

large main sewers, therefore, the provision for rainfall is governed more by the maximum fall during a period of several hours, while in smaller sewers it is governed by the maximum in half an hour or even less. The smaller branch sewers approximate to the condition of house drains, where provision may sometimes be required (see Part I, Chapter V) for rainfall at the rate of three inches per hour.

In connection with the sewerage of Manchester, a most interesting series of records, taken by an automatic gauge, has been tabulated by the late Mr. de Courcy Meade, City Surveyor. For fourteen years prior to the publication of the record (in 1914) the duration and intensity of each rainfall was recorded, and the information thus obtained was used in the preparation of the new main drainage scheme. The results are not necessarily applicable elsewhere, but it was found desirable there to provide for a rainfall at a rate of about a quarter of an inch per hour lasting three hours, a rate of half an inch per hour for about an hour, a rate of one inch per hour for twenty minutes, and a rate of one and a quarter inches per hour for 15 minutes. These do not represent the actual extremes recorded, but only the provision which it was thought reasonable to make. A rate of $1\frac{3}{4}$ inches per hour was recorded for 15 minutes, $1\frac{1}{2}$ for 45 minutes, and nearly an inch for an hour and a quarter.

Occasionally there are rainfalls of altogether exceptional severity. In June, 1917, a fall of nearly 10 inches in 24 hours was recorded at Bruton in Somerset, while a large area of country had from 4 to 6 inches in the same period. In connection with the Louth disaster of 29th May, 1920, it was recorded that at Hallington a fall of 4·7 inches occurred in $2\frac{1}{2}$ hours.

To provide for such rainfalls by enlarging the sewers is out of the question.

Relief by Storm Overflows.—The method of providing this relief is discussed in detail in Chapter XV, but its effect on the size of sewers may be considered here.

It may be taken as a universal rule that wherever there is a town requiring sewerage there is a stream which may take the

unpolluted rain-water. It is usually admitted further, that when sewage is diluted to a certain extent it becomes permissible to discharge the surplus beyond a certain volume into the stream, just as if it were clean water. The required dilution may vary according to the circumstances, but the assumption is that as the stream is itself swollen it may receive without offence an accession of very dilute sewage. This gives a means of relieving sewers from an unknown burden.

But the full measure of relief by storm overflows is only applicable to main sewers, and the smallest branches get none. A branch sewer must take whatever rain-water or sewage enters it, and it is only after the combined volume has been carried for some distance that it reaches a storm overflow. A storm overflow can only be constructed where some other watercourse is available to receive the water rejected from the sewer. It follows then that every sewer from its beginning down to the point at which it reaches a storm overflow must be of such capacity that it can carry everything that reaches it. The limitation of " six times the dry weather flow " (see below) does not apply here, as though legally permissible it is not physically possible to get rid of any water until a suitable outlet for a storm overflow has been reached.

" Six Times the Dry Weather Flow."—The Local Government Board (England) following the researches and reports of the Royal Commission on Sewage Disposal, adopted a working rule that works of sewage disposal should be able to treat (wholly or partially) six times the dry weather flow (" D.W.F.") of sewage. It follows therefore that sewers, after making all allowance for relief by storm overflows, and allowing for any subsequent increase in the population drained to the works, must be capable of carrying that quantity to the outfall. This is a conclusion of great value to the sewerage engineer. Formerly he was very much in the dark as to the provision he should make, but now he can with confidence limit his sewers—that is, those which are relieved by storm overflows—to a size sufficient to deal with six times the dry weather flow, allowing of course for any prospective increase in that flow. Instead of working absolutely in the dark, with the fear that he might go seriously astray

in his estimate of size, he has now something quite clear and definite, and can meet adverse criticism by pointing to the official requirements.

" **Standard** " **Sewage.**—One town may have a much larger water consumption than another, and accordingly may produce a larger volume of weaker sewage. 100 gallons per head on the one hand, and 15 gallons on the other, are not unknown. Given an equal number of inhabitants and therefore an equal production of *sewage material*, one town will produce six or seven times as much *sewage* as the other : in other words, the undiluted sewage (or D.W.F.) of the one town will be as weak as the sewage of the other when mixed with the allowance of rain-water which would seem to justify its discharge by storm overflows. It would be absurd to argue that the weak sewage must be diluted with rain-water in the same proportion as the other, and the natural conclusion is that the Commissioners had in view sewage of average strength.

Without presuming to set up a standard, it might be said that from 25 to 30 gallons per head is a fairly common allowance, and it would seem reasonable to provide sewers on this basis, that is, that six times the D.W.F. is from 150 to 180 gallons per head per day. But on the other hand, the state of the stream is to be considered, as the discharge of rain-diluted sewage is justified not only by the dilution of the sewage but by the swollen condition of the stream. If the normal sewage of a town was 180 gallons, if would not do to say that it was only one-sixth the strength of standard sewage and so might be discharged untreated. It would, however, be fair to say that the town discharged a mixture of one part of sewage (30 gallons) with five parts of clean water (150 gallons) and that in estimating " six times the D.W.F." the former only should be reckoned. The maximum quantity to be treated would thus be 30×6 of sewage $+150$ of water, or 330 in all. If the normal flow were 90, then the limit would be 30×6, $+60$, or 240 in all. But in places producing such dilute sewage it is evident that circumstances are exceptional, and that it is not possible to apply fairly any stock rules. The above figures are only given as rough suggestions.

Capacity of Sewers and of Sewage Works.—These should have some relation to each other, but where future growth is anticipated it is much more important to make sure that the *sewers* can deal with the increase than to have the *sewage works* of sufficient size. It is a very serious matter to find that a main sewer is too small : the only way of increasing its capacity is to take it up and relay it. It is therefore of great importance to make sure that it is big enough at first for any reasonable increase. The objection to having it too big for present requirements may be met to some extent by admitting for the time being more rain-water—or water from some other source—than would be admitted under the final conditions of working. The storm overflows for example might be set to come into action not at six times the present dry weather flow, but something like what that would be in the future. The sewage works could deal with this to some extent, as they also would be designed to meet a certain amount of growth : but the admission of extra water cannot be carried very far, as the filters are not designed much ahead of present requirements. The tanks, like the sewers, should be ready for a considerable increase—though not to the same extent —while the filters can easily be extended as required, provided that space has been left for the purpose.

Other Factors Governing Size.—The chief factor, in addition to the work the sewer has to do, is the available gradient. This of course is got from levelling, and while in the preliminary stages of design the gradient can only be known approximately, it is not as a rule difficult to get a fairly close approximation. The gradient and the quantity to be discharged being known, it is easy to get by calculation or from tables (see Chapter IV) the required size of sewer.

CHAPTER IV

VELOCITY OF FLOW IN SEWERS

THE velocity of flow depends on a number of factors, of which the following are of special importance :—

1. The character of the liquid.
2. The internal surface of the sewer.
3. The gradient.
4. The " hydraulic mean depth," sometimes called " hydraulic radius."

1. The Character of the Liquid.—It is usually assumed that this is sufficiently uniform to be taken as constant, no correction being made unless the sewage is very abnormal. There is no doubt that this factor may cause substantial variation, and that the velocity of flow diminishes as the strength of sewage increases ; but this is met in practice by the usual estimate of velocity being somewhat low, and by the scouring effect of occasional rushes of dilute sewage. It is a direction in which experiment might be useful.

2. The Internal Surface of the Sewer.—This was entirely ignored until comparatively recent times, the same formulæ being used for every kind of surface. So long as surfaces of the same general character were in question no great harm was done : but cases have been recorded where a rough channel followed a smooth one in the same conduit, both being of the same carrying capacity by the old calculation, and where the rough channel proved quite inadequate to carry off the water which the smooth one brought down. In practice it happens more frequently that a smooth channel such as a pipe is put in to supersede a rougher

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channel, and as its real carrying capacity is much greater than is calculated, no harm is done except that the smooth channel is made much too big.

Considerable attention is now given to what is termed the " coefficient of roughness," but velocities are still calculated largely by rule of thumb. The chief difference is that while the engineer used to refer to tables of velocity calculated on the old system, he now refers to tables calculated on the new, without paying much attention to the coefficient of roughness on which they are based. The result is better, but as a standard co-efficient runs through the tables, the advantage to be gained from smoother channels is often unnoticed. While the use of tables is of great value in saving time, it is important to know their basis, and to modify the figures if it is found that the co-efficient used in calculating them is larger or smaller than is to be expected in the particular case. There should be no difficulty in getting, for the smaller sewers, pipes which will give a smaller coefficient than that usually assumed.

3. **The Gradient.**—This is in British practice expressed as a proportion of vertical to horizontal, the vertical being unity, thus—1 in 25, 1 in 317, and so on. It is sometimes put in frac-tional form, $\frac{1}{25}$, $\frac{1}{317}$, the numerator being the vertical and the denominator the horizontal. In American practice it is usually given as a percentage : the gradient described in Britain as 1 in 50 would in America be called a 2 per cent grade. Obviously, the steeper the gradient—or in other words the smaller the hori-zontal distance for a given fall—the faster will be the flow. The velocity is approximately in proportion to the square root of the gradient.

4. **The " Hydraulic Mean Depth " or " Hydraulic Radius."**— The former term is more convenient for general use, but when circular channels are in question the latter is often preferred. In what follows the former is used throughout : in Part I, which dealt exclusively with pipes, the latter was used. The two terms are synonymous, and simply mean the average depth, every part of the channel which is in contact with the liquid

being reckoned as bottom. It is found by dividing the sectional area of the liquid by the wetted perimeter. For instance, if the

Fig. 5.—Hydraulic Mean Depth, Rectangular Channel.

rectangular channel in Fig. 5 is 1 foot broad, and the depth of liquid is 3 inches, the sectional area of the liquid is one-quarter of a square foot. The " wetted perimeter " (or wetted " girth ") is one foot for the bottom and one-quarter of a foot for each of the two sides, making altogether $1\frac{1}{2}$ ft.

The hydraulic mean depth therefore is $\frac{1}{4} \div 1\frac{1}{2} = \frac{1}{6}$ of a foot.

If a circular channel of any size (Fig. 6) is half-full, the sectional area $= \frac{\pi r^2}{2}$ and the wetted perimeter $= \pi r$ the hydraulic mean depth therefore $= \frac{r}{2}$, that is, half of the actual radius. If the circular channel were full both the sectional area and the wetted perimeter would be doubled, and the hydraulic mean depth would be unaffected. Thus it is usual in tables and in calculations to say that these are based on " full or half-full." If the channel is less than half-full the hydraulic mean depth is less, and may become very small indeed, even in a large channel. If on the other hand, the channel is between half-full and full the hydraulic mean depth is greater, its maximum value being when the depth of flow is approximately four-fifths the diameter of the channel. It is then about 0·6 instead of 0·5 of the radius, and this increase may be taken into account in those cases where the flow of water is sufficient to produce this depth. It is much more common, however, to find cases where for long periods even the half-full condition is never reached, and a corresponding deduction from the " full or half-full " velocity ought therefore to be made.
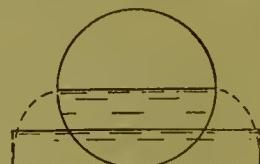
Fig. 6.—Hydraulic Mean Depth, Circular Channel.

Calculation of Velocity of Flow.—In making calculations, the first of the above-mentioned factors—the character of the liquid

—will not be referred to further than to say that if for any reason the liquid is more viscous than sewage of moderate strength the ordinary rules are not fairly applicable, and allowances which can only be judged by experience must be made. It is to be observed that this is not a question of weight : two liquids differing only in weight—however widely—will flow at the same rate, as the effect of gravitation and inertia vary in equal proportion. But if one is less limpid than the other, either from its own nature or from the presence of dissolved or suspended matter, then the less limpid will flow more slowly. Strong sewage may readily flow more slowly on this account.

The most commonly accepted formulæ for the calculation of velocity have been based on the assumption that this was proportional to the square root of the gradient and of the hydraulic mean d p h, the typical formula being $V = C\sqrt{RS}$.

where   V = velocity in feet per second,
R = hydraulic mean depth (or radius) in feet,
S = the gradient expressed as a fraction,
C = an experimental " constant."

In the older formulæ C was regarded as invariable, and its value was usually taken as anything between 90 and 100.

In the more recent formulæ two lines of progress are to be noted. In the one (exemplified by Kutter's formula) the endeavour has been to obtain an expression which (by the insertion of the appropriate experimental values) will be applicable to all sorts and sizes of channels : in the other the endeavour has been to standardise these values for the ordinary conditions of sewers, and so to produce a formula which will be simpler than the others with of course a more limited application.

Kutter's Formula.—This is usually regarded as the best expression of general application, but it is cumbersome in form and somewhat laborious when numerous calculations are required. It is the result of very extensive analysis of special experiments and of recorded practical results, the examples given numbering over 2000. Its method is to calculate a value for C in the equation given above.

The equation for this purpose is $C = \left\{ \dfrac{41 \cdot 6 + \dfrac{1 \cdot 811}{n} + \dfrac{\cdot 00281}{S}}{1 + \left[\left(41 \cdot 6 + \dfrac{\cdot 00281}{S}\right) \times \dfrac{n}{\sqrt{R}} \right]} \right\}$

where C, R, and S are as above, and where n is the " coefficient of roughness."

It will be observed in calculating the value of C by this method, that there is not only introduced the new quantity n, but that the values of R and S occur. In other words, it is no longer assumed that the velocity varies merely as the square root of these quantities, but they produce an effect on C as well. Thus the old idea that if the product of the gradient and of the hydraulic radius is constant the velocity will be constant is not supported by this calculation, which would justify much flatter relative gradients for large channels, and steeper ones for small channels, than the old rule would have done.

When it is necessary to compare the discharging capacity of channels of dissimilar character, the best method is to examine these channels in the light of the detailed information on which Kutter's formula is based. The record of these is to be found in the published work of Ganguillet & Kutter (the English translation is entitled *Flow of Water in Rivers and other Channels*, and is published by Macmillan & Co.) and a study of these investigations will not only give valuable information as to the character of different surfaces, but will indicate the very wide limits which must be allowed in any such calculations. Channels which from description seemed to be of very similar character were found to give results which differed widely, and the figures prove the necessity of allowing an ample margin of safety.

When the surface of the channels under consideration is of *similar* character, the engineer may choose his coefficient of roughness once for all. In fact, it has been chosen for him by various writers, who have compiled tables based on one coefficient.

On p. 36 are given some specimen values of n, selected from the list just mentioned. It will be seen that while the range from the highest to the lowest is very great, the variation among the possible surfaces of properly made sewers is comparatively

small. If therefore the formula is used for the purpose of ascertaining the probable flow in a sewer about to be constructed, the engineer can determine the coefficient of roughness within fairly narrow limits. In calculated tables it is commonly taken as ·013, which is probably a fair average, but is on the one hand too low for an ordinary brick sewer, and on the other hand is too high for well-glazed stoneware or fireclay pipes. It might be correct for such a pipe if the surface had become roughened by deposit, but when kept in good order either by natural flow or otherwise it would be quite fair to assume a lower coefficient. The accompanying tables and the relative curves on pp. 37 to 41 are calculated on the basis of ·012, and cover all the usual sizes of glazed pipes. For brick sewers ·013 or ·014 would be more suitable.

It is to be noted that while the required calculations are tedious, they are in no way difficult, and it is well to make a trial calculation for various coefficients of roughness, gradients, etc., in the course of designing any system of sewers. By comparing the results with the tables it will be seen to what extent the velocity will be affected by any possible variations.

Santo Crimp's Formula.—As an example of the other type of formula that of Santo Crimp may be given, the meaning of the symbols being the same. This may be regarded as applicable specially to the case of large sewers, built of brick.

$$V = 124 \sqrt[3]{r^2} \sqrt{s}.$$

Sewers needlessly Big.—It ought to be unnecessary to refer to the blunder which was frequently made in old days, of putting in a large sewer for the sake of getting a faster flow, irrespective of the amount of liquid to be conveyed. There is reason to suspect that the blunder is still made, and a special warning may not be out of place.

A reference to the accompanying tables or any of the numerous similar tables, indicates that the larger the sewer, the less is the gradient required to give a certain velocity. This is well-known to everybody who has to do with sewer construction. But the calculations are made on the assumption that the sewer is running at least half-full, and when a large sewer is used for a small flow

the result is a small hydraulic mean depth and therefore a low velocity. The result of using a sewer which is too big for its work is not only extravagance, but also lessened efficiency, as the diminished velocity means greater tendency to deposit, and probably offensive smells. The apparently easy method of increasing the velocity by increasing the size of the sewer is an absolute pitfall, offering no temptation to the engineer who knows the principles on which his work depends, but full of danger to the man who works by rule of thumb.

SOME VALUES OF n IN KUTTER'S FORMULA

Glass pipe (average)	·0078
Lead pipe (average)	·0076
Earthenware pipe	·0111
Wrought iron pipe (tubes about 1-in. diam.) .	·0074
Do. (large riveted pipe)	0150
Cast iron pipe (tar-coated, about 4-in. diam.) .	·0078
Do., 4-ft. water main, asphalt coated . . .	·0134
Semicircular channel in neat cement . . .	·0103
Do., $\frac{2}{3}$ cement and $\frac{1}{3}$ very fine sand . . .	·0111
Brick channel with smooth surface . . .	·0121
Hammer dressed ashlar	·0133
Large river, rough channel, up to . . .	·0540

Figures in common type represent velocity in feet per second, thus : 8·27. Figures in Bold type represent discharge in cubic feet per second, thus : **·722**.
Pipe running full in each case.

GRADIENT 1 IN —

Diam. in ins.	6	8	10	12	15	20	25	30	35	40	45	50	55	60	65	70	75	80	90	100	125	150	175	200	225
4	8·27 **·722**	7·16 **·625**	6·40 **·559**	5·845 **·510**	5·23 **·4566**	4·53 **·3955**	4·05 **·3536**	3·695 **·323**	3·42 **·299**	3·20 **·279**	3·02 **·264**	2·86 **·250**	2·73 **·238**	2·61 **·228**	2·51 **·219**	2·42 **·211**	2·33 **·203**	2·26 **·197**	2·13 **·186**	2·02 **·176**					
5		8·62 **1·176**	7·71 **1·052**	7·04 **·960**	6·30 **·859**	5·45 **·743**	4·88 **·666**	4·45 **·607**	4·12 **·562**	3·85 **·525**	3·63 **·495**	3·445 **·470**	3·28 **·447**	3·14 **·428**	3·02 **·412**	2·91 **·397**	2·81 **·383**	2·72 **·371**	2·56 **·349**	2·43 **·331**	2·17 **·296**	1·98 **·270**			
6			8·93 **1·754**	8·15 **1·601**	7·29 **1·432**	6·31 **1·239**	5·65 **1·110**	5·15 **1·011**	4·77 **·937**	4·46 **·876**	4·21 **·827**	3·99 **·784**	3·80 **·746**	3·64 **·715**	3·50 **·687**	3·37 **·662**	3·26 **·640**	3·15 **·619**	2·97 **·583**	2·82 **·554**	2·52 **·495**	2·30 **·452**	2·13 **·418**		
7				9·20 **2·459**	8·23 **2·200**	7·125 **1·905**	6·37 **1·703**	5·82 **1·556**	5·38 **1·438**	5·04 **1·347**	4·75 **1·270**	4·50 **1·203**	4·29 **1·147**	4·11 **1·099**	3·95 **1·058**	3·80 **1·016**	3·67 **·981**	3·56 **·952**	3·35 **·895**	3·18 **·850**	2·84 **·759**	2·59 **·692**	2·40 **·6415**	2·24 **·599**	2·11 **·564**

GRADIENT 1 IN —

Diam. in ins.	25	30	35	40	45	50	55	60	65	70	75	80	90	100	125	150	175	200	225	250	300	350	400	450	500
8	7·07 **2·469**	6·45 **2·252**	5·97 **2·084**	5·59 **1·951**	5·27 **1·839**	4·99 **1·742**	4·76 **1·662**	4·56 **1·592**	4·38 **1·529**	4·22 **1·473**	4·08 **1·424**	3·95 **1·379**	3·71 **1·295**	3·53 **1·232**	3·15 **1·100**	2·88 **1·005**	2·66 **·929**	2·49 **·869**	2·35 **·820**	2·22 **·775**	2·03 **·709**	1·88 **·656**			
9	7·74 **3·420**	7·07 **3·124**	6·54 **2·889**	6·12 **2·704**	5·77 **2·549**	5·47 **2·417**	5·22 **2·306**	4·99 **2·205**	4·80 **2·121**	4·62 **2·041**	4·46 **1·971**	4·32 **1·909**	4·07 **1·798**	3·86 **1·705**	3·45 **1·524**	3·15 **1·392**	2·92 **1·290**	2·73 **1·206**	2·57 **1·135**	2·44 **1·078**	2·22 **·981**	2·05 **·906**	1·92 **·848**		
10	8·30 **4·576**	7·66 **4·178**	7·09 **3·867**	6·63 **3·616**	6·25 **3·409**	5·93 **3·234**	5·65 **3·082**	5·41 **2·951**	5·20 **2·836**	5·01 **2·732**	4·84 **2·640**	4·68 **2·552**	4·41 **2·405**	4·19 **2·285**	3·74 **2·040**	3·42 **1·865**	3·16 **1·723**	2·95 **1·609**	2·78 **1·516**	2·64 **1·440**	2·41 **1·314**	2·23 **1·216**	2·08 **1·134**	1·96 **1·069**	
12	9·63 **7·563**	8·79 **6·904**	8·14 **6·393**	7·61 **5·977**	7·17 **5·631**	6·81 **5·349**	6·49 **5·097**	6·21 **4·877**	5·97 **4·689**	5·75 **4·516**	5·55 **4·359**	5·38 **4·225**	5·07 **3·982**	4·81 **3·778**	4·30 **3·377**	3·92 **3·079**	3·63 **2·851**	3·39 **2·663**	3·20 **2·513**	3·03 **2·380**	2·77 **2·176**	2·56 **2·011**	2·39 **1·877**	2·25 **1·767**	2·13 **1·673**

GRADIENT 1 IN —

Diam. in ins.	100	125	150	175	200	225	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000	1100	1200	1300
15	5·67 **6·958**	5·07 **6·222**	4·63 **5·682**	4·28 **5·252**	4·00 **4·909**	3·77 **4·627**	3·58 **4·393**	3·26 **4·001**	3·02 **3·706**	2·82 **3·461**	2·66 **3·264**	2·52 **3·093**	2·40 **2·945**	2·30 **2·823**	2·20 **2·700**	2·12 **2·602**	2·05 **2·516**								
18	6·48 **11·451**	5·80 **10·249**	5·29 **9·348**	4·90 **8·659**	4·58 **8·093**	4·31 **7·616**	4·09 **7·227**	3·73 **6·591**	3·45 **6·096**	3·23 **5·708**	3·04 **5·372**	2·88 **5·089**	2·75 **4·860**	2·63 **4·647**	2·52 **4·453**	2·43 **4·294**	2·34 **4·135**	2·27 **4·011**	2·20 **3·888**	2·13 **3·764**	2·08 **3·676**	2·02 **3·570**			
21	7·25 **17·438**	6·49 **15·610**	5·92 **14·239**	5·48 **13·181**	5·12 **12·315**	4·83 **11·618**	4·58 **11·016**	4·18 **10·054**	3·85 **9·260**	3·61 **8·683**	3·40 **8·178**	3·23 **7·769**	3·07 **7·384**	2·94 **7·072**	2·82 **6·783**	2·72 **6·542**	2·62 **6·302**	2·54 **6·109**	2·46 **5·917**	2·39 **5·749**	2·33 **5·604**	2·26 **5·436**	2·16 **5·195**	2·06 **4·955**	
24			6·50 **20·420**	6·01 **18·881**	5·62 **17·656**	5·30 **16·650**	5·03 **15·802**	4·59 **14·420**	4·24 **13·320**	3·91 **12·472**	3·74 **11·750**	3·54 **11·121**	3·38 **10·619**	3·23 **10·147**	3·10 **9·739**	2·99 **9·393**	2·88 **9·048**	2·79 **8·765**	2·70 **8·482**	2·63 **8·262**	2·55 **8·011**	2·49 **7·823**	2·37 **7·446**	2·27 **7·131**	2·17 **6·817**

GRADIENT 1 IN —

| Diam. in ins.	200	225	250	300	350	400	450	500	550	600	650	700	750	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	2000
27	6·12 **24·334**	5·76 **22·902**	5·47 **21·749**	4·99 **19·841**	4·61 **18·330**	4·31 **17·137**	4·06 **16·143**	3·85 **15·308**	3·67 **14·592**	3·51 **13·956**	3·37 **13·399**	3·25 **12·922**	3·14 **12·485**	3·04 **12·087**	2·86 **11·372**	2·71 **10·775**	2·58 **10·258**	2·47 **9·821**	2·37 **9·423**	2·28 **9·066**	2·20 **8·747**				
30			5·88 **28·863**	5·37 **26·360**	4·96 **24·347**	4·64 **22·776**	4·37 **21·451**	4·15 **20·371**	3·95 **19·389**	3·78 **18·555**	3·63 **17·819**	3·50 **17·180**	3·38 **16·591**	3·27 **16·051**	3·08 **15·119**	2·92 **14·333**	2·78 **13·646**	2·66 **13·057**	2·55 **12·517**	2·45 **12·026**	2·37 **11·634**	2·29 **11·241**	2·22 **10·897**	2·15 **10·554**	2·04 **10·014**
36				6·08 **42·97**	5·63 **39·796**	5·26 **37·181**	4·96 **35·060**	4·70 **33·222**	4·48 **31·667**	4·29 **30·324**	4·12 **29·123**	3·97 **28·062**	3·83 **27·073**	3·71 **26·225**	3·49 **24·669**	3·31 **23·397**	3·15 **22·266**	3·01 **21·276**	2·89 **20·428**	2·79 **19·721**	2·69 **19·015**	2·60 **18·378**	2·52 **17·813**	2·45 **17·318**	2·32 **16·399**

Curves of Velocity and Discharge, Calculated from Kutter's Formula with
$n = \cdot 012$.   I.   Sewers from 4″ to 7″ diameter
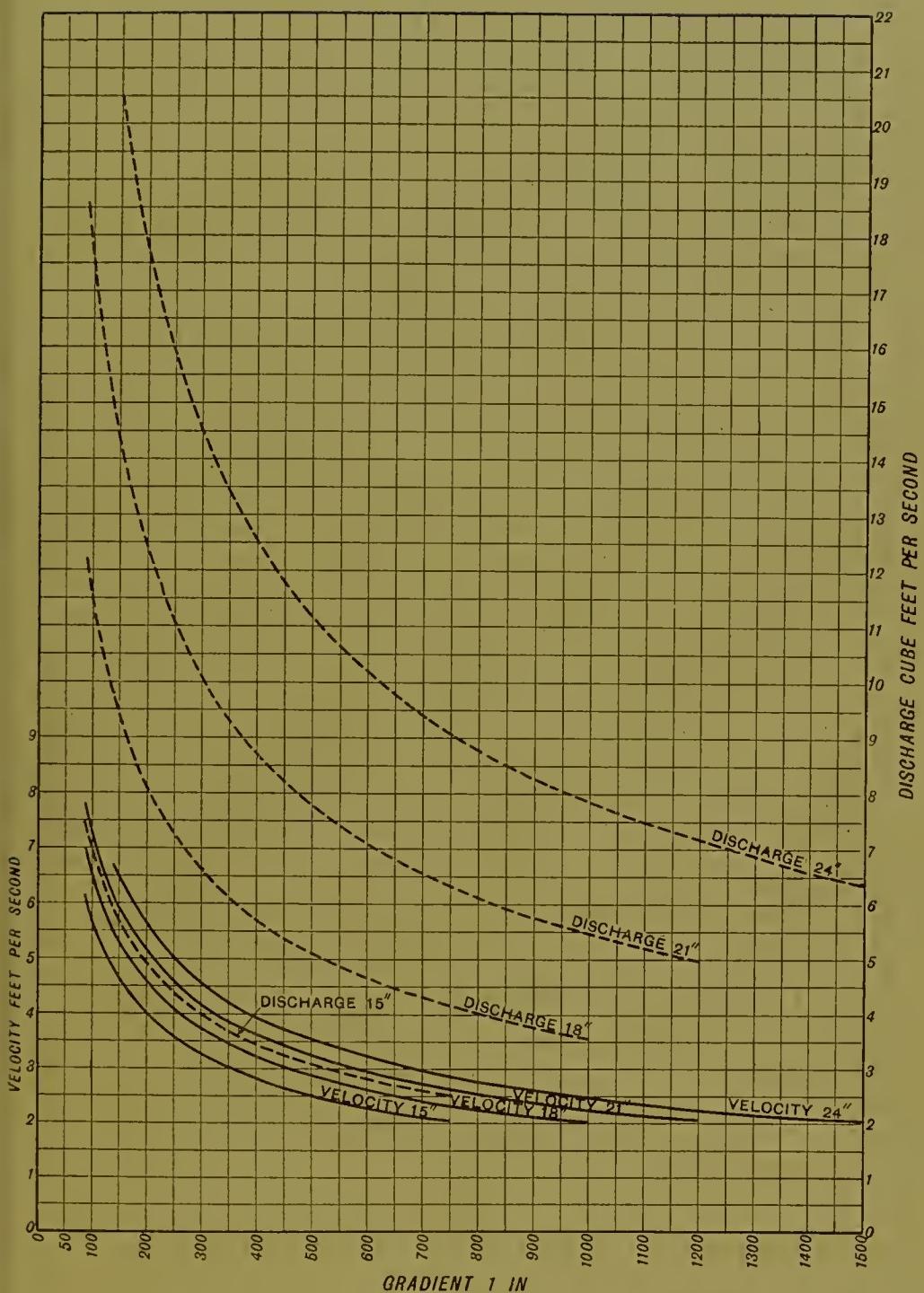
Curves of Velocity and Discharge, Calculated from Kutter's Formula with $n = \cdot012$.
II. Sewer from 8″ to 12″ diameter.
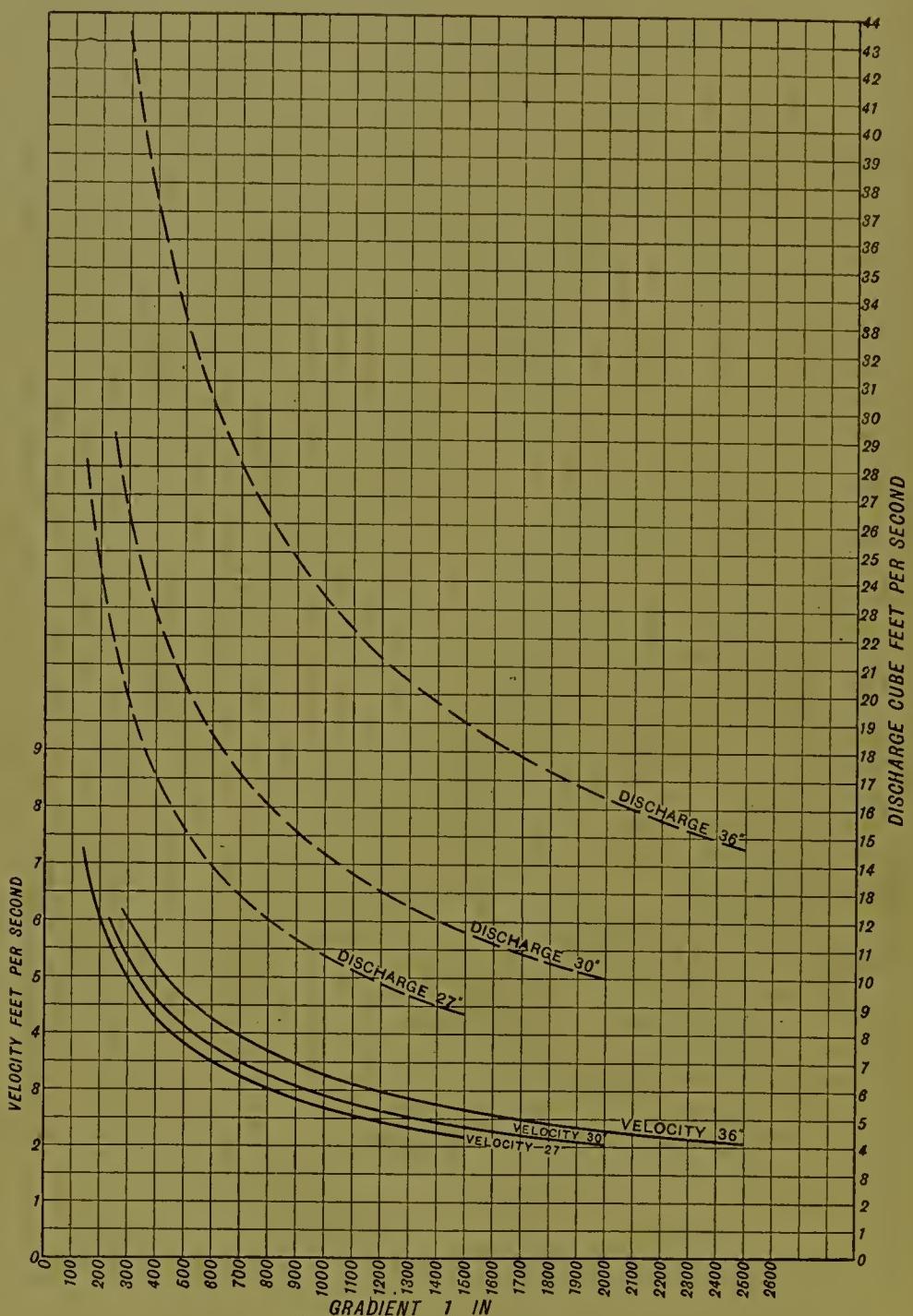
Curves of Velocity and Discharge, Calculated from Kutter's Formula with
$n = \cdot 012$.   III.   Sewers from 15″ to 24″ diameter.

8·0

7·5

7·0

6·5

6·0

6·5

5·0

4·5

4·0

3·5

3·0

2·5

2·0

1·5

1·0

0·5

0

DISCHARGE CUBE FEET PER SECOND

10

9

8

7

6

5

4

3

2

1

0

VELOCITY FEET PER SEC.

VELOCITY 6"

DISCHARGE 12"

VELOCITY 12"

DISCHARGE 10"

VELOCITY 10"

DISCHARGE 9"

DISCHARGE 8"

0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400 420 440 460 480 500

GRADIENT 1 IN
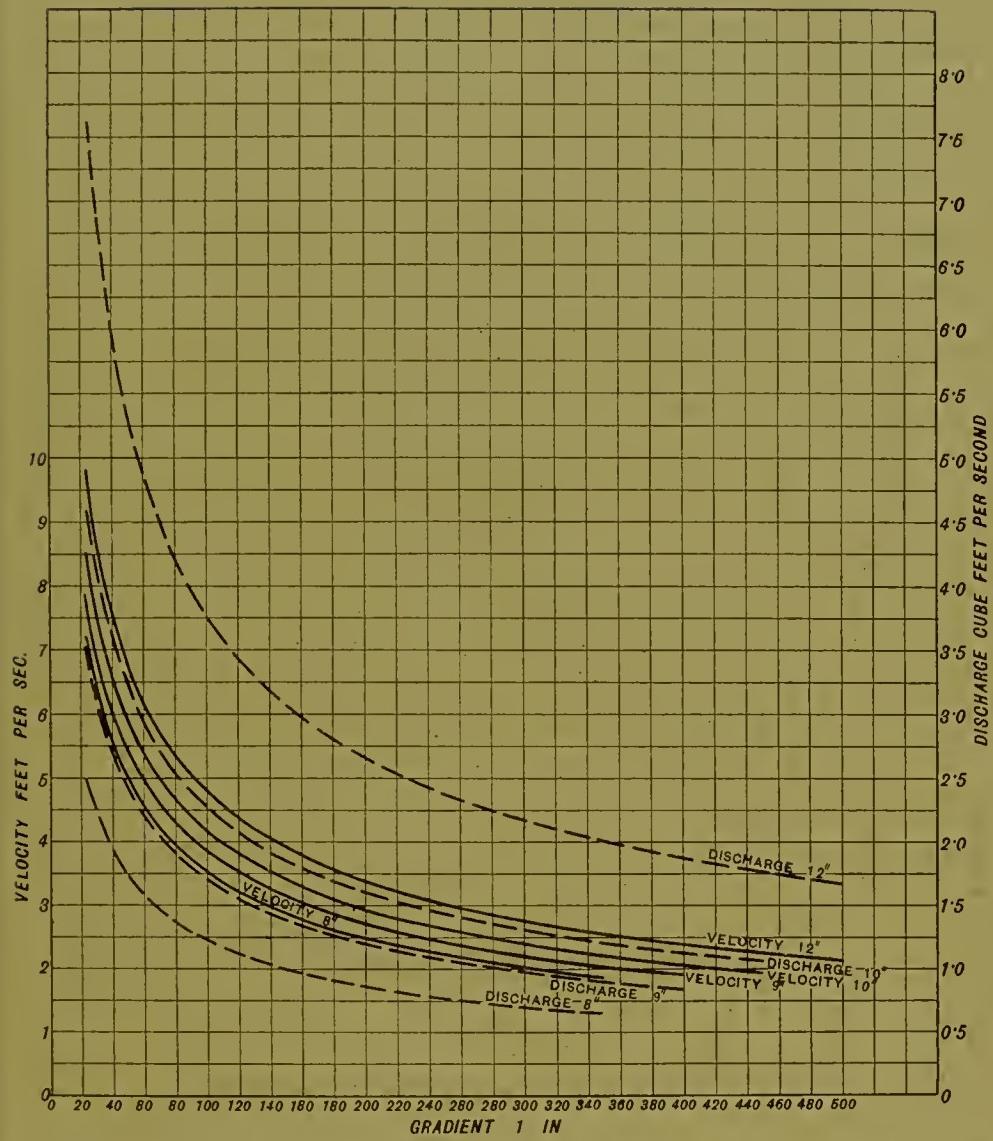
Curves of Velocity and Discharge, Calculated from Kutter's Formula with $n = \cdot 012$.
IV. Sewers from 27″ to 36″ diameter.

CHAPTER V

Principles of Flushing.—The velocity of flow, as already explained (p. 33) is dependent chiefly on the hydraulic mean depth and the gradient. When the gradient is large, a small hydraulic mean depth will give sufficient velocity : when it is small, a greater hydraulic mean depth is needed.

But this hydraulic mean depth must be actual and not merely possible. A 12-inch pipe, for example, has a hydraulic mean depth of 3 inches when it is running full or half-full, and of nearly four inches at the best ; but if the same pipe is running only with an inch or two of water in the bottom, the hydraulic mean depth is very much less. This is not unusual, it is the normal state of affairs in many sewers. It is not so marked in fully built urban areas as in areas where the sewers, in view of future extension, are large in proportion to present needs. In the latter it may readily happen that even the maximum flow is insufficient to give a good velocity, while the minimum daily flow is a mere dribble. If this is combined with a flat gradient, the natural results are sluggish flow, dirty sewers, and smells. The conditions under which such sewers act are really very similar to those of house drains—often with no flow at all, and seldom with a flow approaching their full capacity. But while a house drain is carefully laid with a gradient of 1 in 40 or 50, such a sewer—receiving perhaps only one or two house drains over a considerable distance—is expected to work at a gradient of 1 in 200 or 300, or it may be less. No wonder, therefore, that there is trouble.

Limitations of Flushing.—It seems often to be assumed that any sewer however flat will be satisfactory if it has a flushing tank at its head, and that no sewer will be satisfactory which is

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not so provided. The second assumption leads to nothing worse than extravagance : the first has more serious results.

If the gradient is such that when the sewer is running say half-full it has something more that a self-cleansing velocity ; and if, by flushing, the sewer can be supplied with sufficient water to produce such a flow often enough and for a long enough time to wash away any deposit which may have gathered between the flushes ; then flushing may be entirely satisfactory. If the sewer is so flat that even when it is running at its best depth the velocity is no more than self-cleansing, then flushing is no good unless it is continuous. If on the other hand the gradient is such that the flow of even a small depth produces sufficient velocity, then flushing is unnecessary.

There are therefore two limits to the efficacy of sewer flushing. The gradient may be so good that the ordinary flow gives sufficient velocity either continuously or at frequent intervals : flushing is then unnecessary. It may be so flat that no flushing will give the required velocity : in such a case flushing is useless. The utility of flushing lies between these two limits. When the dry weather flow is sufficient to produce a satisfactory velocity there is no need for flushing : when a half-full flow will not produce a sufficient velocity, flushing will do no permanent good.

It might quite fairly be added that it is seldom possible to maintain the " half-full " condition over any great distance, and therefore it is taking rather too favourable a view to assume that flushing will be successful if " half-full " would give a fair velocity. A margin must be given for removing the material already deposited, which requires more power than merely to prevent deposit. Of course in theory rather more than half-full would give a better result, but this is still more difficult of attainment. If sewage matters are to be driven along a flat sewer by flushing, the only way to do it is by means of relays of tanks. A succession of flushing tanks, each delivering water into the sewer with some velocity, might serve the purpose, but probably it would in such a case be cheaper to pump the sewage, and so to avoid the flat gradient.

Flushing Tanks.—The method of flushing is to collect water

in a tank, and then suddenly to release it in considerable volume. The amount thus delivered, and the method of delivery, are both of importance.

Automatic Discharge.—The general principle is that water is collected from a slow flow, and suddenly discharged by some automatic means. Syphonic discharge is almost universally adopted.

When an ordinary round pipe syphon (Fig. 7) is used for such a purpose, it is found that although it works quite well when the
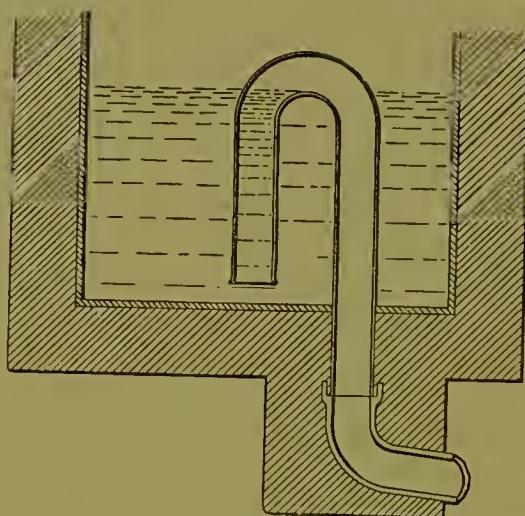

FIG. 7.—Round Pipe Syphon.

tank is fed by a strong flow, it is useless for a small feed. If the flow into the tank is slow the water merely overflows smoothly through the syphon and no sudden discharge takes place. The first successful attempt to get over this difficulty was that of the late Rogers Field, who devised the syphon which
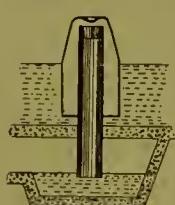

FIG. 8.—Rogers Field's Syphon.

bears his name, and which is illustrated in Fig. 8. Its chief feature was the shallow trap or water seal into which the leg of the syphon dipped, and which prevented the return of any air which was displaced. In combination with this the upright leg of the syphon had a lip at the top, so that any water trickling

over could not flow smoothly down the side, but fell in drops
through the central tube, displacing the air as it fell. The func-
tion of the shallow water seal was to prevent the readmittance
of the displaced air, and the slight
diminution of pressure inside the
syphon caused the water to flow
over more freely, thus displacing
air more rapidly and starting the
syphon. This type of syphon was
for a time very popular, but the
deep-seal syphon of Mr. Adams has
largely superseded the older type.

The Adams type of syphon (Fig. 9
shows its elementary form) acts by
increasing and not by diminishing
the pressure. The syphon consists,
like the other, of an upright centre tube surmounted by a
dome ; but in place of delivering into a shallow receptacle it
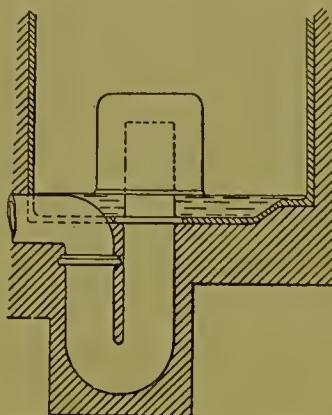
FIG. 9.—Deep Seal Syphon
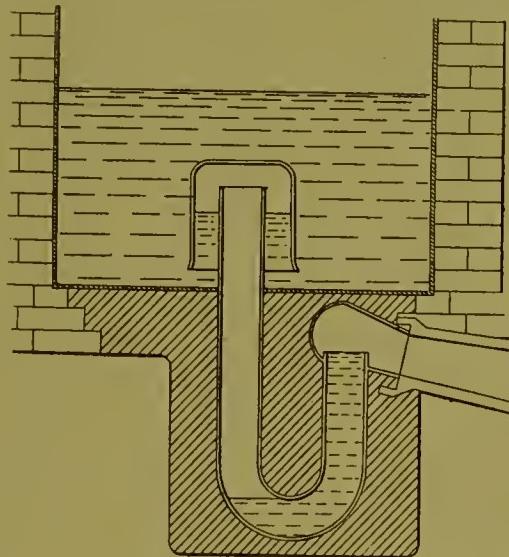
FIG. 10.—Deep Seal Syphon about to Discharge.

terminates in a deep trap. It will be observed, too, that it does
not come into action until it is submerged to a considerable
depth, while the older syphons were never submerged at all.

The action is as follows : The water rises in the tank until it reaches the lip of the dome. No sooner is this lip submerged (in this elementary form) than the air in the dome and tube is imprisoned between the water in the tank and that in the trap on the outlet, and as the water continues to rise in the tank this air is compressed. Ultimately the condition shown in Fig. 10 is reached. The trap is on the point of giving way, and as the water continues to rise, however slowly, the pressure increases, with the result that a bubble of air is forced past the trap. The escape of this bubble reduces the pressure inside the syphon,


FIG. 11.—Deep Seal
Syphon with Air Pipe.

and the water is at once forced over into the upright shaft in full volume. The action of this type of syphon is much more certain than that of the older type, and in one or other of its forms the deep seal syphon is almost universally used.

It is usual, however, to have some accessories. With the form above illustrated, it is possible that the syphon after discharge might go on slowly discharging if a slow feed were coming into the tank, the result being that the tank would never be filled and the water would simply dribble through. This is met by adding an air pipe as shown in Fig. 11. It will be observed that this air pipe gives a means of regulating the time of discharge, because the sealing up of the air in the dome, and the consequent commencement of compression, only takes place when the water level reaches the outside end of the air pipe. By shortening this pipe, therefore, the compression of the air and the discharge of the tank are deferred until a larger volume has been accumulated in the tank, and conversely, the discharge can be accelerated by using a longer air pipe, up to the point at which the end of the air pipe is nearly as low as the lip of the dome.

The primary purpose of the air pipe is to prevent the continuing action of the syphon. The air pipe is so small that the air which it admits has no effect on the action of the syphon when discharging in full volume, but when that volume has passed the air enters
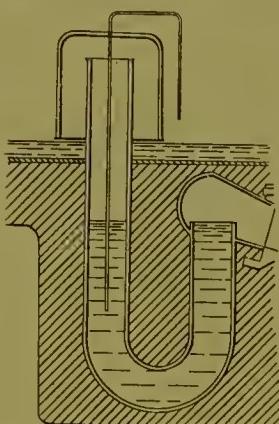
and restores the pressure, even while a small flow of water is running. There is then no difference in pressure inside and outside the dome, and as there is nothing to force the water up into the dome the action at once stops.

Another modification is the " Miller " free outlet now often combined with the Adams syphons (Figs. 10 and 11). The effect of this is to allow the water to fall away freely from the rising leg of the syphon, and thus to accelerate the discharge.

Flushing Water.—Flushing should be done by means of fairly clean water—not necessarily fit for general supply purposes, but at least free from any gross pollution. The old system of flushing by means of the sewage itself is obsolete : the flow was stopped by a penstock in the sewer so that a section gradually filled, and the sudden release of this sewage caused a scour. But the sewage while gathering was depositing its suspended matter on the invert, and was fouling the walls, so that the effect was prejudicial rather than beneficial. The water used for flushing may be got from such sources as (a) the ordinary town supply ; (b) stream or spring water collected in the vicinity of the tank ; (c) waste water, say, from a drinking fountain ; (d) tolerably clean discharge from some industrial process—pit water for example, or (e) an old gravitation supply, superseded for ordinary domestic use. So long as it is fairly free from suspended and from putrescible matters, its purity otherwise is of no great consequence.

Quantity to be Discharged.—For flushing effect, the quantity should be as large as possible. On the other hand, it is not desirable to add greatly to the volume of sewage which has to be treated : the water in many cases must be used economically : and it may be very inconvenient to construct a large tank. Balancing the conflicting requirements, the following is regarded as a fair allowance under ordinary conditions :—

<pre>
      For a 9 in. sewer 300–400 gallons.
        ,, 12 in.   ,,   400–600   ,,
        ,, 15 in.   ,,   600–800   ,,
        ,, 18 in.   ,,   800–1000   ,,
</pre>

For the reasons already explained, flushing is most likely to be needed on the sewers of smallest size, unless where on account of prospective developments sewers are put in much larger than immediate requirements would justify. The above figures do not represent anything more than a general indication and may be varied very widely. With shallow sewers it is often difficult to get a tank of sufficient capacity without making it of inconveniently large area, and thus making it very expensive. In streets, the strength of the tank roofs is a matter of great importance.

Example of Flush, Compared with Ordinary Flow.—The following table is a fairly instructive illustration of what may happen in a sewer, with or without flushing. It records a series of experiments made by the author a number of years ago, on a sewer which was the cause of much complaint because of smells. It was nine inches in diameter, and while at the top it had a good gradient, it had for a long distance a gradient of only 1 in 450. The reference letters are : A, the upper extremity, at which a large flushing tank was situated ; B, a manhole midway on the steep gradient ; C, a manhole at the end of the steep gradient ; D, E, F, and G, manholes on the flat gradient. The distance between manholes may be taken as about 100 yards. Where blanks occur in the table the velocity could not be ascertained : otherwise it was got by observing the first indication of extra water in the case of the flush, and by coloured water, etc., in the other cases.

Section.	Velocity of Flush.	Velocity of ordinary flow.
	(Both in feet per minute.)	
A—B	205	—
B—C	252	—
C—D	140	10
D—E	105	14
E—F	96	—
F—G	70	41

The effect of the flush could not be traced any further.

It will be observed that while the velocity of the flush gradually fell off, the velocity of the ordinary flow gradually increased

This was no doubt due to the fact that various branches contributed to the volume, so that the contents of the sewer, which at D formed a mere trickle, had at G developed into a tolerable flow. This may be taken as a typical case of a sewer so flat that no amount of flushing would keep it clean, unless the flushing water were delivered into it with considerable velocity at various parts of its course. It will be readily understood that the smaller velocities were very rough approximations, and that even the best of them was far short of what is regarded as " self-cleansing." But the fact that such a sewer had served for years, and had not developed any serious obstruction, shows also that the rules about self-cleansing gradients and velocities may be stretched to a very considerable extent without the sewers becoming actually silted up.

CHAPTER VI

SEWER EXCAVATIONS

Depth of Sewers.—The depth of any sewer is determined primarily by the depth of the drains with which it has to connect. In a large town, where cellar drainage must be taken into account, the minimum depth is seldom less than ten or twelve feet, and often very much more. In a rural district the depth may in comparison be trifling : if the ground in which the sewer is laid is lower than the adjoining ground, and if there are no houses with cellars, a depth of three or four feet may meet all the needs of the house drains. Even in a rural district it frequently happens that deep sewers are needed to take the house drains—for example, the ground on which the house stands may be low, or the house may be at a distance from the sewer, or there may be a long drain round the house—and in any of these cases the private drain may be a deep one before it reaches the point where it can be picked up by the sewer. In the central streets of a large town the sewers are almost inevitably deep ; in the outskirts, and in rural districts, they may possibly be shallow.

The depth depends also on the contour of the ground through which the sewer has to pass. While the general system of sewers is always laid out so as to follow as much as possible the natural contour of the ground, this cannot possibly be done in complete detail. The natural surface of the ground may be very irregular, and the line which would give a continuous fall is usually very tortuous. Sewers must run in tolerably straight lines, they must suit the lines of street or road, they are bound rigidly to gradient, and their routes—other than the general direction—are determined by conditions with which surface levels have often little to do. The result is that the required depth varies enormously, and that deep excavations on the one hand and banking on the

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other are ordinary incidents in the construction of sewerage work. No other branch of engineering—except canal engineering—is so exacting and uncompromising. Water mains may be carried up or down hill, roads and railways may have their gradients adjusted to suit the natural conditions, but sewers must have a minimum fall in the required direction.

Structurally, the most desirable depth for a sewer is that which will afford sufficient protection against the weight and impact of traffic, without imposing a heavy load of soil. Financially, the most desirable depth is that which will meet the above requirement with the minimum of work—in other words, at the least depth. Practically, the engineer lays out his sewers so as to pick up all the necessary connections and then to follow such routes as will just give the required depth and no more—so far as that is practicable. It happens always that considerable variations are inevitable.

Cutting, Tunnelling, and Banking.—The construction of sewers involves or may involve (1) Open cutting, (2) Tunnelling, and (3) Banking. Each of these will be considered in detail.

" Soft " and " Rock " Excavation.—This distinction may have a great effect on the cost, and can only be very roughly estimated in advance. It is common to provide in the" Bill of Quantities " or " Schedule " (see Chapter XVII) for two rates, either entirely separate or one as an extra over the other, the distinction being between " soft " or ordinary cutting and " rock." In parts of the country where specially hard rock such as " whin " (basalt) may be encountered, it is not unknown to have this mentioned as a third class—soft, ordinary rock, and whin—but this is the exception : it is more common to have only the two.

The classification is at best very rough-and-ready. Specifications often enlarge on the classes of material which are or are not to be counted as rock, and this if intelligently done is very useful : but practically, " soft " excavation may mean anything from running sand (which is much more troublesome than most rock) to material which can scarcely be got out with the pick ; while

rock may be anything from the softest sandstone to the hardest
basalt or granite. Pricing for sewer excavation is among the
difficult and speculative parts of contractors' work, and large
sums may be made or lost by what might seem to be very
trifling variations in the character of the material encountered.

Nature of Surface. –This may be anything from paved streets
to agricultural or even waste land. It is usual to assume that
in ordinary macadam roads, agricultural land, or waste land,
the contractor will take the cost of breaking and afterwards
restoring the surface into account as part of his excavation
costs, and so long as this is made quite clear it is reasonable.
On the other hand, when paved streets, or even tar macadam
in any of its numerous varieties, come to be disturbed, it is right
that a special item should be put in for what may be a very
serious part of the cost. Even the cost of breaking an old and
solid macadam crust may be substantial, and it is often found
much easier to get labourers for trench work in open fields than
in town streets. It is desirable therefore if no special allowance
is scheduled for surface work, to avoid slumping together in one
category work of dissimilar kinds. There is, for instance, no
objection to classifying a certain section of sewer excavation
merely as so many yards of cutting to various enumerated depths,
so long as it is all through macadam roads or all through agricul-
tural land : but it is better to separate the parts if some is of the
the one kind and some of the other.

Trenches in Good Ground.—Good ground is that which can
be excavated with reasonable facility, and which does not readily
fall in. It includes sand or gravel when dry and firm, and clay
which is neither too soft nor too tough ; even rock which is not
very hard may be " good " from the excavator's point of view.
When rock works easily and is only just hard enough to justify
the term it is often the most desirable material that the contractor
can find—he gets the rock price and has no trouble about keeping
up the sides of his trenches.

In good ground, if the trench is not deep and if no great delay
is incurred between opening and refilling, it may not be necessary

to put in any supports. In sound rock this is quite usual. If any support is necessary it is of a simple character, such as that illustrated in Fig. 12. The only danger is that of large lumps falling out of the side, and in good material it is easy to judge when such an event is possible. The struts are sometimes put in quite irregularly, one being used wherever in the judgment of the foreman in charge safety demands it.
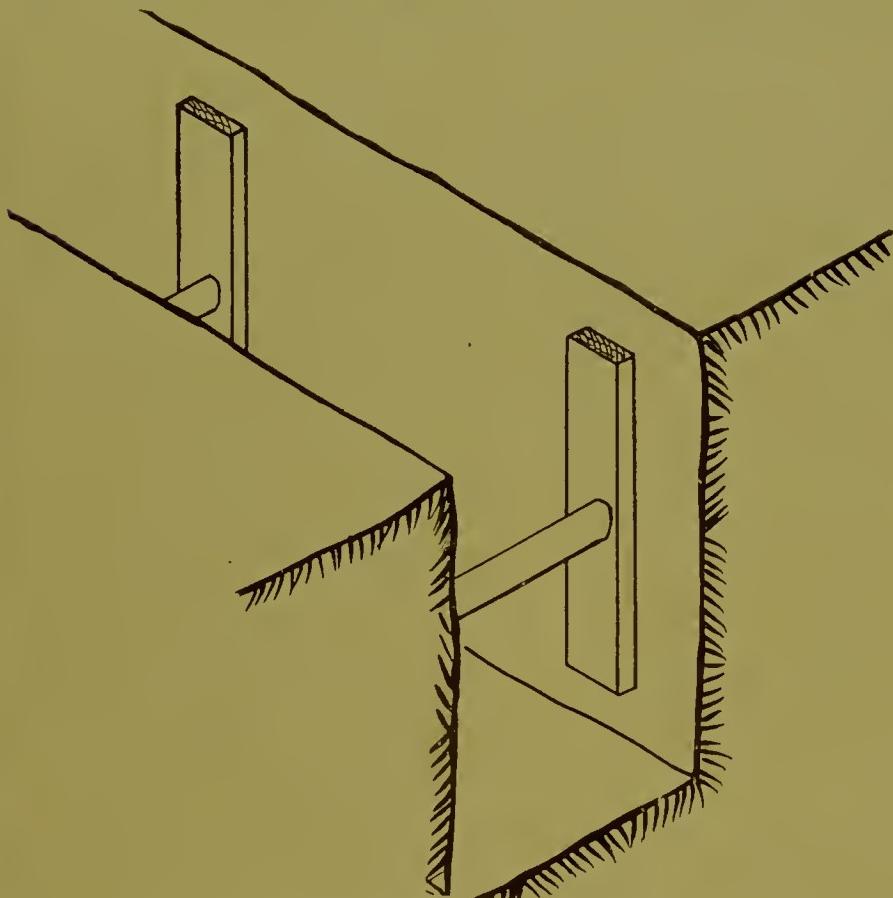

Fig. 12.—Trench in Good Ground

Trenches in Medium Ground.—When the ground is such that a more complete system of protection is needed, but still fairly sound and firm, the method shown in Fig. 13 is used. Here the setting consists of long horizontals or " wales " kept apart as before by struts. These wales sometimes bear directly on the side which they are to support, being merely a horizontal instead of vertical variety of the method shown in Fig. 12 ; but as a

rule they are used when more support is wanted, and are then, as in Fig. 13, backed by short " poling boards." The poling boards are kept hard against the sides by means of wedges, driven in sufficiently to give the required pressure. It is to be understood that the pressure is simply that required to keep the timber in place and to prevent any *beginning* of movement. The function of the timber is not to push the side back, but to prevent it coming forward.
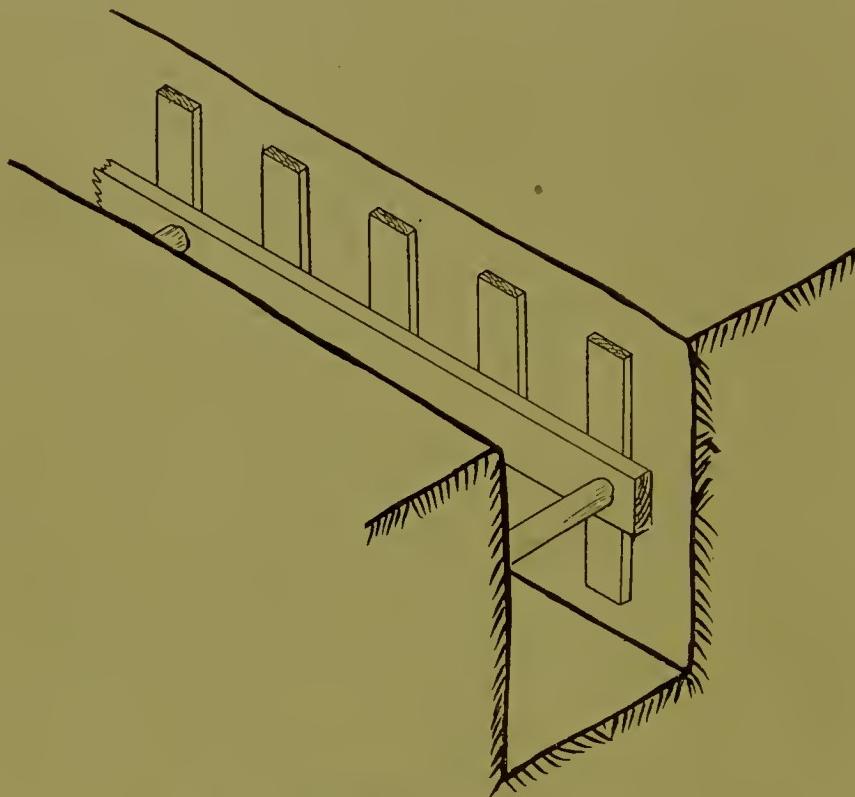
FIG. 13.—Trench in Medium Ground.

Trenches in Bad Ground.—When the material is such that a continuous support is needed, the timbering assumes the form of " close sheeting," as in Fig. 14. The struts and the wales remain as in the last case, but instead of separate poling boards there is a system of boards covering the entire side of the trench. The object of this is to avoid any escape of even the smallest material, which with a substance such as loose sand is very likely to occur. If this should occur even to a small extent, the result

is to loosen the whole of the timbering by the formation of cavi-
ties behind it, and this may cause a sudden and complete collapse.
In cuttings of moderate depth, where the contractor is anxious
to minimise the use of timber, and where no very serious results
would follow a collapse, it is very common to see trenches of moist
sand left with less than complete sheeting, in the hope that before
it dries and thus becomes loose the work may be completed and
the trench be ready for refilling. If so, there is a substantial

Elevation.   Section.
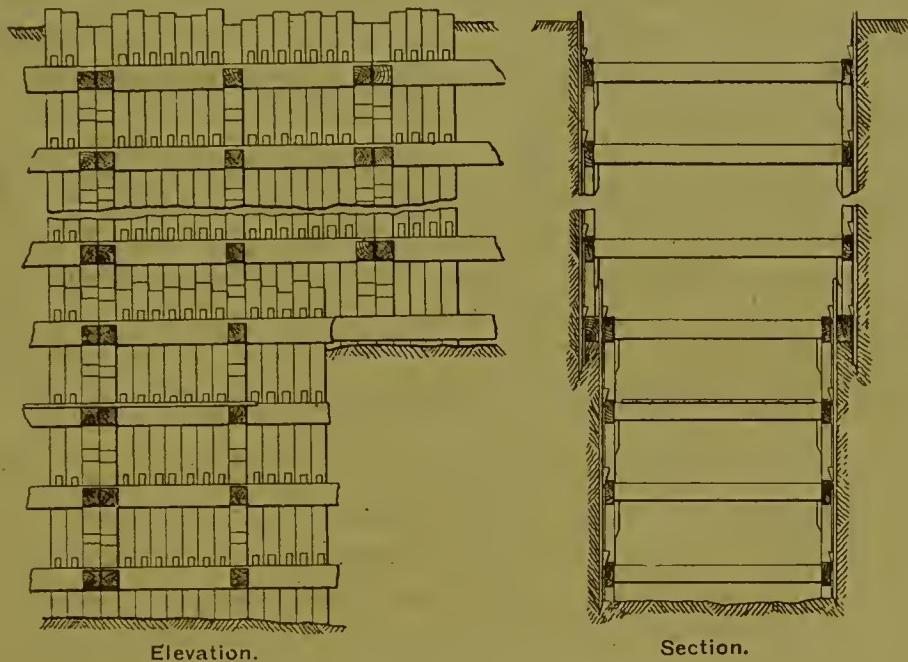
Fig. 14.—Trench with Close Sheeting.

saving, and moist sand stands fairly well. But if anything occurs
to cause delay, and if the timbering has been of an open kind, then
the dry sand pours out through the interspaces, the cavities
thus formed extend behind the timber, and the whole affair
comes down. Close sheeting is intended to obviate this risk,
which may occur not only in the circumstances described but
with any material which is (either at first or by drying or wetting)
liable to run. It may be added that some materials—of which
very fine dry sand or saturated sand of any size are typical
examples—are very difficult to keep in place by the most careful
sheeting. " Running sand," which is sand so saturated that it

runs like a viscous liquid, is exceedingly difficult to control, as
it rises in the bottom of the trench besides coming in from the
sides. The method usually adopted is to expedite as much as
possible all the operations, so that the pipes may be laid, jointed,
and secured in position before any serious movement has taken
place. Everything is in readiness before the last part of the cut-
ting is done, and the bottom (in short lengths) is then rapidly
sunk to the required depth, the pipe laid and jointed, and then
packed in and covered. In such cases some of the special joints
described in Chapter VII are most useful, as the ordinary cement
joint is in such circumstances very apt to be damaged before
it has time to set.

Adjacent Buildings.—When the track is in the neighbourhood
of buildings, and especially when these are of a heavy and sub-
stantial character, it is of great importance to see that the sup-
ports are such as to make movement of the sides impossible. In
such a case no makeshift of any sort will be tolerable, and the
trench must be substantially timbered with heavy material.

Examining and Photographing Buildings.—When trenches have
been cut alongside buildings, it is natural that damage will be
carefully looked for by the owners, and cracks are very often
found. These may or may not have existed before the operations
were commenced, and claims in respect of them may be made
quite erroneously though in good faith. A properly authenticated
record of the appearance of the buildings before the work com-
menced may be most valuable evidence, either to prevent or
to rebut a claim. A personal survey by an architect of standing,
or a set of photographs, or both, is a most satisfactory asset.
Of course all particulars as to date, etc., must be carefully pre-
served, and evidence on all the necessary points, including that of
the photographer who took the photographs, must be available.

TUNNELLING

This is a special branch of excavation, and in its full detail it
is much beyond the scope of the present volume. In sewer work
(except in short stretches) it is seldom adopted unless the depth

from the surface is at least 16 feet. The following method, however, is often adopted in shallower cuts.

Tunnel and Open Cut in Short Alternate Sections.—When the depth exceeds 7 or 8 feet, and when the subsoil is of such a nature that a short heading—say, 5 or 6 feet long—can be driven without timber, there are advantages in making the surface opening discontinuous. Each open cut of, say, 10 or 12 feet is followed by 5 or 6 feet of tunnel, in which the surface crust is left undisturbed (Fig. 15). The amount of material to be handled is less, and the uncut part forms a useful support or strut, which is specially valuable when there are heavy buildings alongside the trench. The diminished volume of stuff to be shifted is of course offset
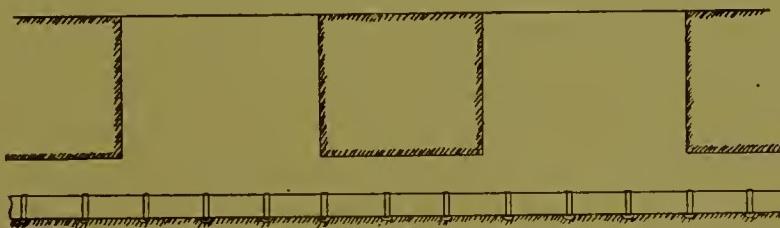
Fig. 15.—Alternate Tunnel and Open Cut.

to some extent by the more costly method of working; but although the actual saving in cost may be negligible, the contingent advantages may make it worth while. On the other hand, the surface is irregular owing to the succession of broken and unbroken parts, and the road authorities do not always approve of this method. A further objection is that the ramming of the tunnelled parts may not be sufficiently thorough to prevent ultimate settlement of the crust, with the result that the surface remains irregular for a long time. This latter objection has most weight when the operations are carried on through streets : in cultivated ground it is of no consequence. It may be said generally that the advantage of this alternate method of working increases with the depth, until a depth is reached at which continuous tunnelling is desirable.

Minimum Depth for Tunnelling.—The minimum depth at which tunnelling is undertaken depends on considerations other than

economy. The authority (or the official) responsible for the up-
keep of the road is anxious to have its surface damaged as little
as possible, but if any damage is to be done he wishes to know of it
at once. When tunnelling is done at a small depth the surface
layers are of moderate thickness, and while they may support
the road for a time, they are insufficient of themselves to support
it permanently. If the excavated material is replaced in a care-
less fashion, it does not (after it consolidates) nearly fill the space :
and even with careful ramming there is sure to be a certain
amount of subsequent consolidation leading to voids. It is for
this reason that as a rule tunnelling is not permitted unless the
depth is considerable, 16 feet being an ordinary limit. It might
often pay the contractor to tunnel at a less depth : and the objec-
tion which the road surveyor has in view—that the damage if
any would only become apparent after the lapse perhaps of years
—is not always a disadvantage in the eyes of the contractor.

In a busy town street the lessened disturbance of traffic may
make tunnelling desirable even when the depth is small, and when
the other considerations would favour open cut.

Shafts and Headings.—Shafts are sunk at intervals depending
on the depth, the size of the tunnel, and the nature of the surface ;
and headings are driven between these shafts. The deeper the
tunnel the fewer the shafts, from considerations of economy. The
larger the tunnel, the fewer will be the shafts, because a large
tunnel can be driven economically for a greater horizontal dis-
tance from the shaft bottom than can a small one. If the tunnel
is driven under important streets the shafts will be limited in
number to avoid disturbance of the street and interference with
traffic.

Wherever possible, shafts are sunk on the site of permanent
manholes, and in such positions they do not add to the cost.
The excavation for the shaft is ultimately used in building the
manhole. Any purely temporary shafts are a direct addition
to the cost. The timbering follows the same rules as in excava-
tion, and the shaft must be large enough to permit the con-
venient removal of excavated material.

A paper read before the Aberdeen Association of Civil

Engineers (*Minutes of Proceedings*, Vol. II) on " Deep Trenches and Small Tunnels," by Mr. Henry Gregory, dealt very fully with these matters in relation to sewerage work. By the courtesy
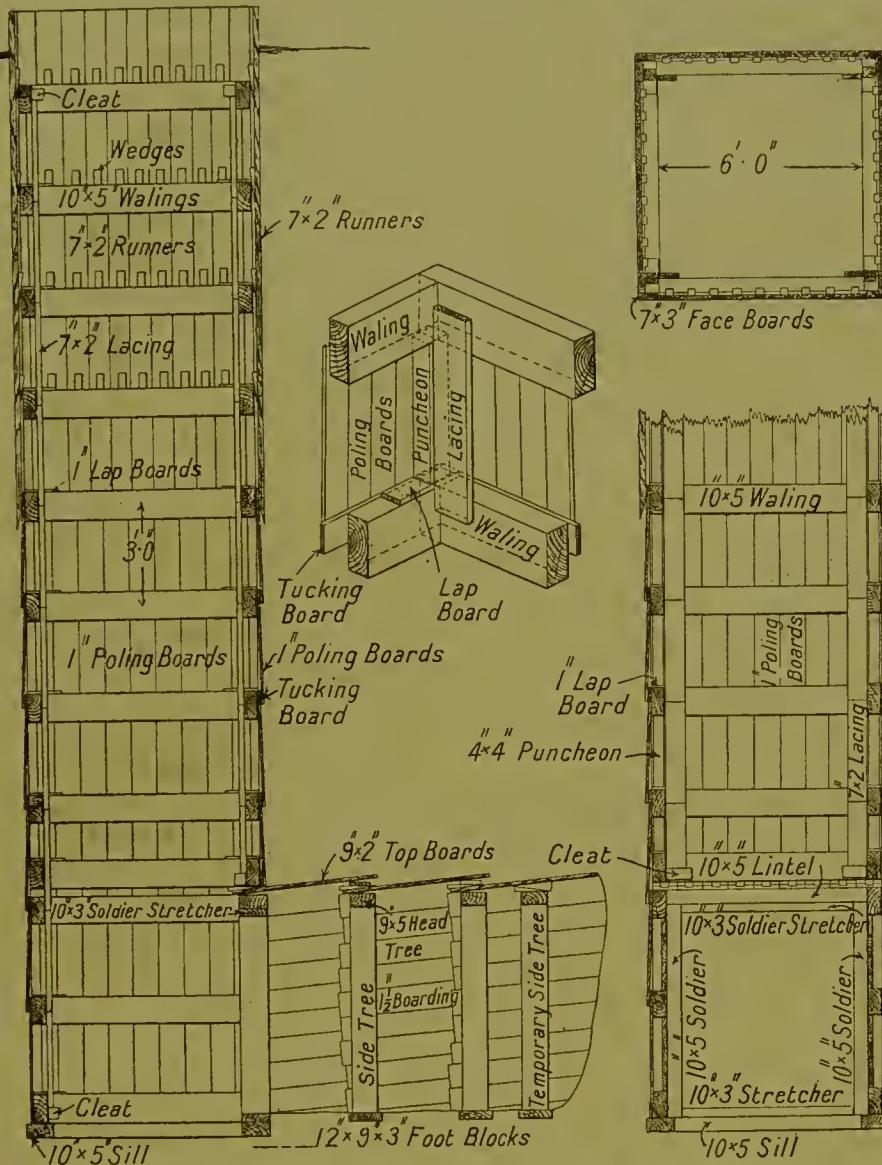

Fig. 16.—Tunnel Shaft.

of the Association and of Mr. Gregory the author has drawn freely on that paper and its illustrations. Fig. 16 in particular, showing a shaft and heading, is largely based on Mr. Gregory's work, although in form it differs somewhat from his illustration.

Tunnels in Ordinary Ground.—For a pipe sewer the size of heading is simply the minimum in which a man can work to advantage both before and after the pipe is in its place. However small the pipe, it will seldom be less than 4 ft. 6 in. by 2 ft. 6 in. The timbering must be set so as to leave a free way for the pipe, and in ordinary cases it is desirable to avoid timbering on the floor. Fig. 17 shows a common method.
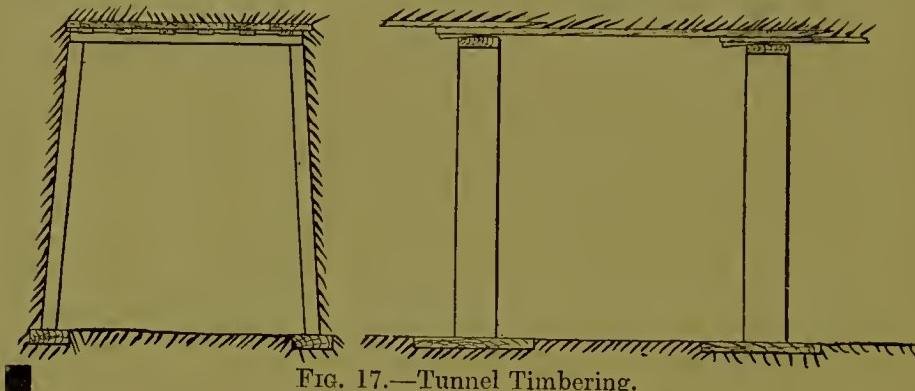
Fig. 17.—Tunnel Timbering.
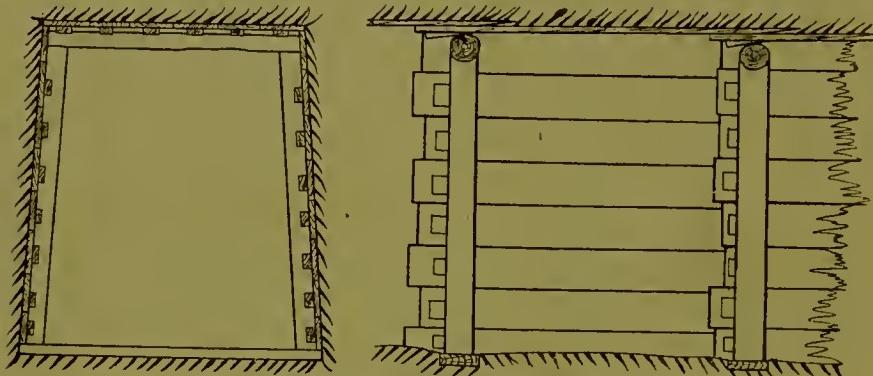
Fig. 18.—Tunnel Timbering, Close.

Tunnels in Soft Ground.—So long as the ground will stand long enough to admit of effective timbering, there is no material difference in the method; but the timbering will be closer and more substantial than if the ground were firm. Close sheeting is often necessary, and it is obvious that in tunnelling operations the consequences of any slip may be much more serious than a small slip in the open : it is therefore essential that no chances should be taken (Fig. 18).

Tunnelling in Water-logged Ground.—Up to certain limits, this can be done by ordinary timbering combined with natural drainage or pumping. When these means fail, recourse may be had to compressed air, but the cost of this is a serious item in any but large works. It is used in combination with the " Great-head shield."

Tunnelling with Shield.—This is used in tunnels of considerable size, and consists of a cutting edge of steel, of the same size and shape as the outside of the tunnel lining, which is driven forward
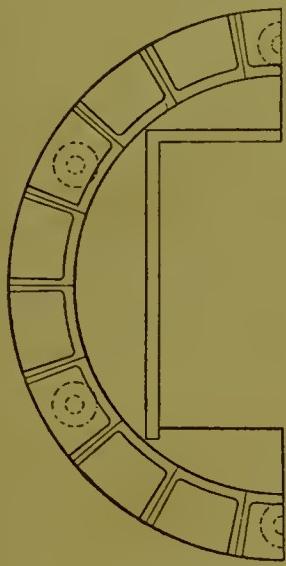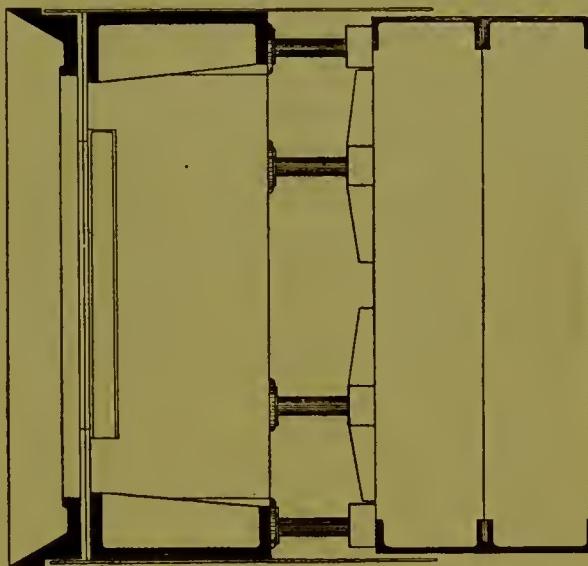
Half Elevation.　　　　**Longitudinal Section.**

FIG. 19.—Shield.

by hydraulic pressure (Fig. 19). The tunnel lining (iron sections or brickwork) is constructed inside the tail of the shield, and as the shield is moved forward in successive steps the lining is kept close behind it. There is thus only the face exposed, the danger of the sides or roof falling in being entirely absent. As the shield progresses the core is removed from the face. This method of construction is specially applicable when the tunnel is being driven through such material as plastic clay. It may be advantageously used in any soft material, and combined with compressed air it allows tunnels to pass through strata which without it would be impossible. Compressed air is used when the strata

contain water in such quantity as to impede the operations, and especially when the material runs with the water. In such circumstances an " air-lock " is constructed some distance back from the face, and the water or running material is held back by the pressure of air being made sufficient to resist its pressure, Puddle clay is used when necessary to concentrate the pressure of the air over the required face.

This method of working need not be discussed in detail, as its application to sewerage is limited.

Tunnelling in Rock.—This is a tedious but otherwise a simple operation. The objections to the use of explosives, which are sometimes serious in the case of sewer work in towns, are not so great in the case of tunnels as in open cut, as the public safety is not endangered : and there is usually nothing to prevent steady if somewhat slow progress. It may readily happen that a tunnel through rock is simpler than a similar tunnel through soft material. The question of timbering will of course depend on the character of the rock, but as a rule a very moderate amount will be sufficient.

Removal of Timber.—This is a point which often gives rise to difference of opinion between contractor and engineer. The timber is put in primarily to facilitate the operations of the contractor and to ensure the safety of the workmen, but when it has served that purpose its injudicious removal may cause trouble through surface subsidence. Hence it is often stipulated that timber is to be left in if ordered by the engineer, the contractor being paid a fixed rate per cube foot for its loss. This rate should not be anything like the value of timber as purchased : it has been cut into short lengths and probably has met with rough treatment, and the value is what such pieces of timber would fetch, less the cost of taking them out. The deterioration forms part of the ordinary cost of tunnelling. In specifying work which includes tunnelling, it is well to fix a price for timber left in and to state it in the specification ; and the endeavour should be to have the rate such that the contractor will be indifferent as to whether it is removed or not. If the price is an

excessive one, then the contractor has a direct interest in having as much as possible left in : if the reverse, he may be anxious to remove timber which ought properly to remain. The engineer, in giving or withholding the order that the timber is to remain, should be as much as possible free from any feeling that he is pressing hardly on the contractor.

The main reason for leaving in the timber (apart from any risk which its removal might involve to those engaged) is to prevent the surface settlement which might otherwise subsequently occur, and especially to avoid injury to adjoining buildings.

Filling up Tunnels.—This is closely associated with the foregoing. The excavated material can never be packed so tightly as it was before being disturbed, and if the walls and roof are treacherous there is a considerable risk that the filling may be very carelessly done. Leaving in the timber allows the filling to be done more leisurely and presumably more carefully, but in a small tunnel, through which a pipe or a built sewer has been laid and of which the remaining space is to be completely filled, effective supervision is very difficult, and a good deal must be left to the men actually doing the work. The material should be thoroughly rammed, and every effort should be made to get as much as possible back into its place. There is necessarily a quantity of surplus material, displaced by the sewer itself, in addition to any resulting from the difference between the original and the final density, and this adds to the difficulty of estimating the quantity actually returned. An experienced inspector, however, will form a pretty fair idea as to whether a proper proportion is going back or not. It has to be remembered that even when the contractor is honestly endeavouring to do his best he is largely dependent on the men who are filling, but in spite of this it is worth while so to frame the specification that it is not to the interest of the contractor to have much surplus material. It may sometimes be made more costly to cart it away than to spend a good deal of time in ramming it back into place as thoroughly as possible.

Filling up Ordinary Trenches.—The first requirement refers specially to pipe sewers, and is that the newly laid sewer is not to

be disturbed : the second is that the ground and the surface shall be restored as nearly as possible to their original condition.

To avoid disturbance, or possible breakage in the case of pipes, it is desirable that the cement joints should be thoroughly set before the earth is filled in. This is not always possible, especially in streets where traffic requirements are of importance and urge immediate filling up of all trenches. In any case, the material which is put next the pipe is selected so as to get soft material which will pack closely round the pipe. Before any material is thrown in (to some extent, indeed, before the joint is made), the pipe should be " shouldered "—that is, it should be buttressed from the two sides of the trench close to the socket by means of material placed carefully in position, even by hand. Soft material is then thrown lightly in, and a man packs it carefully round the side of the pipe, working it in with a spade or shovel and pressing it firmly down, taking care at the same time not to bring any unbalanced side pressure on the pipe. This is continued till the pipe is completely covered. If necessary the material may be wetted to make it pack more freely.

When the pipe has been shouldered and then packed and covered along its whole length, soft stuff may be thrown in carefully, but only when this has become sufficiently thick should any rough material be used in filling. When the cover is a foot thick any ordinary stuff may be safely thrown on to it, but anything specially heavy, such as large stones, should be retained until the filling approaches the surface, this having the further advantage that they do not fall from much height.

In trench filling, it is not uncommon to specify the proportion of fillers and beaters, but it is not easy to ensure that such a stipulation is observed, especially in small and scattered works. The excavated material can never be got into the same space as at first. The natural material has been exposed to the consolidating influence of time, weather, etc., for ages, and it is not possible to arrive at the same result by any rapid means. But careful filling makes a great difference. A trench into which the excavated material is merely thrown loosely will not take nearly the whole of it : beating with rammers during the process of filling makes a considerable difference : especially when combined

with free wetting. The weather has a great influence on the
rapidity of consolidation, a day or two of heavy rain will effect
more than could be done in weeks of dry weather. If trenches
can be filled in wet weather so much the better.

It is usual to hold the contractor responsible for the upkeep
of his work for 12 months after its completion, and the condition
of the trenches is one of the most important points. When the
trench is first filled, it is desirable if possible to leave it somewhat
high ; but of course in many circumstances this is not practicable
to any appreciable extent.

Restoring the Surface.—When the surface consists of paving, the
proper method is to fill the trench with as much care as possible,
and put down the paving in a temporary manner, making it
safe and reasonably convenient for traffic. After a lapse of time
(which depends on the weather, the kind of material, and other
conditions, but which may quite well be about twelve months),
during which time occasional attention and partial restoration
will often be necessary, the material will be so far consolidated
that the surface may be permanently restored. The paving is
then taken up, the trench carefully filled up to the proper level,
and the paving finally laid.

In the case of macadam roads, a certain amount of excess
height may be tolerated at first, and after this has disappeared
and the surface is depressed instead of raised, a new layer of
" metal " is put on. If this is carefully done from time to time,
nothing further is needed, except perhaps final rolling. The thick-
ness of road metal over the trench will be somewhat greater than
elsewhere. If the contractor is under obligation to make good
any depressions by filling them up with road metal found by
himself, he has a very direct interest in seeing that the original
filling is done as efficiently as possible. Any material left over at
that time has to be carted away, and the deficiency has to be made
good later on by the importation of metal. This is probably a
more effectual inducement to thorough ramming than any stipu-
lation as to the proportion of rammers.

In the now frequent case of special road surface, the method
will depend on the exact nature of that surface. If the material

is one which will combine well with a new layer, such as many
forms of bituminous binding, the method is the same as with
ordinary macadam : but if it is a material which requires any
special treatment it may be necessary to use temporary methods
until the consolidation is complete, and thereafter to resurface
properly.

The disturbance of the surface in the case of agricultural
land may not be of such serious moment, and it may be possible
to make arrangements with the owner and occupier which will
obviate any need for further work after the trench has been
filled. But as the consolidation may leave a depression in the
surface soil, it is important to make sure that any surplus
material which is removed during the progress of the work is

Longitudinal Section.   Cross Section.
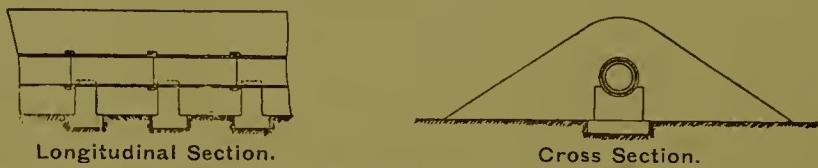
Fig. 20 —Sewer on Piers.

from the subsoil and not from the surface. If this is done, and
all the fertile soil left on the ground, the ordinary course of agri-
cultural operations will before long smooth out any irregularity.

Banking.—If the sewer comes too near the surface, it becomes
necessary to bank over it, or possibly also under it. The latter
case is the more unsatisfactory, as " made " or " forced " soil
is not a good support for the sewer, and it is usually necessary
to provide a bed for the sewer of special material, even if that
has to be imported. If there is at hand material of good quality,
such as clean gravel or sand, and if the depth of support needed is
trifling, it may be sufficient to put in a layer of such material
and to beat it well down ; but if the material is doubtful or the
required depth more than a few inches it may be necessary to
provide a support of continuous concrete or of concrete piers
(Fig. 20). Even a slight settlement may cause serious trouble,
as the result may be fractured pipes, escape of sewage, and
washing away of the supporting soil.

When the sewer rests on the natural soil, but is too near the surface, the banking required is only for cover. In agricultural ground it is usually necessary that there should be a depth of from 18 to 24 inches above the top of the sewer ; this depth varying according to the methods of agriculture, and also no doubt with the personal opinions of those concerned. It is further necessary that the slopes should not be unduly steep if ploughing is to be done over them. Usually it will be necessary

Fig. 21.—Banking over Sewer.

to taper off the slopes at a gradient of about 8 to 1, and if the bank is of any height, the length of slope is considerable even when the sewer rests on the natural surface (Fig. 21). Suppose that a 12-inch pipe rests on the natural surface, that it must have a minimum cover of 20 inches over the highest part of the socket, and that the slopes must not be steeper than 1 in 8, every yard in length will require about 8 cubic yards of banking which will cover about 16 square yards of surface. If the pipe is raised 3 feet above the natural surface, these figures become 32 cubic yards and 32 square yards per yard run. This forms a very

Fig. 22.—Banking Under and Over.

substantial addition to the cost. Even if the required elevation is no more than one foot, as in Fig. 22, the increased work and cost are considerable. Figs. 21 and 22 indicate also, by the outer and inner lines, the difference between the slopes required for agricultural purposes and those which would otherwise be needed. It is sometimes cheaper to pay for the ground required for the minimum banking than to lay off easy slopes. Banking not only means the absorption of a large amount of material (which may be an advantage or the reverse) but it means a great area of ground from which the surface soil must be stripped and on which it must be subsequently replaced.

When the top of a sewer comes unduly near the surface of

a road or street, the methods of meeting the situation (other than regrading the surface) are : (1) Using materials which will withstand the traffic, such as cast-iron or steel pipes, (2) covering the pipes with some protection, such as concrete, or (3) keeping the sewer under the footway instead of the roadway so as to avoid the heavy traffic. These may be combined. When the top of the sewer comes actually higher than the existing surface, then of course regrading is inevitable.

Banking introduces so many contingencies, and so many possible claims for damages, that it is well to avoid it as much as possible. It is seldom wise to incur the trouble and cost unless for the sake of getting safe gradients : if it can be avoided by deeper cutting of the adjoining parts without injury to the gradients it is well to do so.

Intersection of Drains.—Agricultural land is frequently intersected by drains, and when these are cut in sewerage operations care must be taken to restore their continuity, or failing that to provide an intercepting drain. When the sewer trenches are deep it may be necessary to (1) make special provision for the support of these drains where they cross, or (2) return to them and remake the crossing after the trench has become consolidated. When the surface has been raised it is specially important to ensure free drainage under the sewer, otherwise part of the land may be waterlogged and seriously injured.

Interference with Water, Gas, and other Pipes.—In laying out lines of sewer the endeavour is made to interfere as little as possible with existing underground works, but frequently this is unavoidable. When an excavation is being made along a street, the probability of encountering pipes must constantly be kept in view.

Water Mains.—These are of little consequence unless they lie nearly parallel with and close to the sewer route. If they cross the route at other than an acute angle, their approximate position is probably known, and care can be taken in excavating to avoid injuring them. They are usually of such strength that

they are self-supporting in such cases. But when they run close
to the sewer route they increase considerably the risk of a
collapse of the upper part of the trench, and if such a collapse
occurred and caused a fracture of the water main the resulting
escape of water might have serious consequences. If they cross
the track at an acute angle they become unsupported for a con-
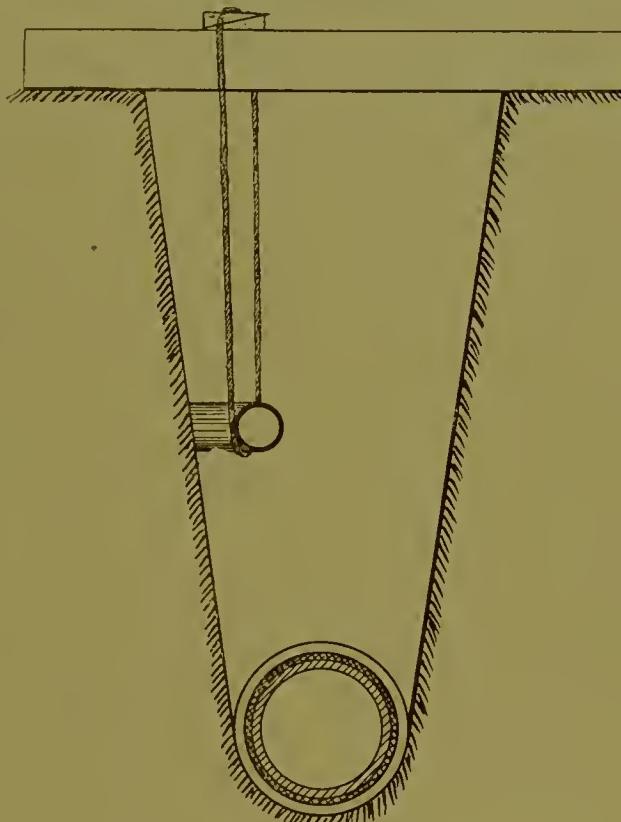
FIG. 23.—Supporting Water Pipe.

siderable length, and special means for supporting them must be
provided. The usual method is to put battens across the trench
and to hang the pipe from these battens while the trench is
open (Fig. 23), and it may be necessary when refilling to build
supports from the bottom up to the pipe, otherwise the gradual
consolidation of the excavated material may bring on the pipe
a load greater than it can bear. A cast iron water pipe is not
fitted to stand as a long unsupported girder, loaded with the
weight of the upper soil and with that of the traffic.

Branch Water Pipes.—In excavating, it is a common experience to find that a pick has been driven through a lead water pipe. It is essential that such an accident should be immediately remedied: the actual cost of the repair is trifling, but the damage caused by the escaped water or by the stoppage of supply might be serious. Anyone engaged in such operations should therefore make provision for dealing promptly with such an accident, by shutting off the water and an immediate repair. The escape of water from a cut lead pipe can be readily stopped for the time by hammering up the pipe, but of course a proper repair is needed to restore the supply.

Gas Pipes.—The mains require the same treatment as water mains. The branches are not quite so easily damaged as the lead pipes used for water, but on the other hand, an accident may not be observed, and the trouble may be deferred to a much more inconvenient season. It is well therefore to keep a close lookout when the work is going on, and to make sure that any breakage is seen and repaired before the ground is filled up.

EXCAVATING BY MACHINERY

Trenching Machines.—Special machines for cutting trenches are largely used in America, but have not come into common use in Britain. Two types have been developed ; in the one a large wheel carries a set of buckets on its periphery, in the other the buckets are carried on a chain. The wheel, or the framing for the bucket chain, is moved in the longitudinal line of the trench to be cut, and the width of the trench is determined by the width of the cutting edge of the bucket. In either case the principle is that of a bucket dredger, and in the chain type the method is precisely similar. The power is provided by a steam or oil engine.

Under favourable conditions, these machines are said to give excellent results, and to show a great economy as compared with hand excavation. Favourable conditions will, however, occur much more readily in America than here. Variations in depth, caused by rise and fall of ground surface, are allowed for by manipulating the adjustment of the cutting parts, and in irregular

ground this demands constant care. The presence of large stones, tree roots, and other obstructions, adds considerably to the cost of operating. Apparently these machines are at their best when trenching for subsoil drains in prairie land, and their profitable application to sewerage work under British conditions would be somewhat limited.

Transporting Machines.—In cutting a trench for laying a sewer, especially when the trench is deep, a substantial proportion of the cost is incurred in raising the excavated material to the surface, storing it there, and subsequently replacing it in the trench. From the contractor's point of view " backfilling " is a great economy. That means in ordinary cases that the construction of the sewer follows the excavation so closely that part of the excavated material is never removed from the trench, but is thrown back over the end of the sewer to cover the completed work. There is from the engineer's point of view the serious objection that efficient supervision is prevented, and at best the interference with the work is such that its application is very limited. By the use of transporters the advantages can be secured without the disadvantages, and in American practice several methods are in use. These take the general form of a cable-way, the differences being chiefly in the method of support. A line of trestles straddling over the trench may be most suitable ; but when it would either be an obstruction, or dangerous owing to treacherous ground, an end supported cable of long span can be used. The cable carries a set of buckets or " skips " : at the excavating end an empty bucket is detached and one which has just been filled by the excavators is attached : the full bucket is raised to the necessary height, carried back along the trench, and its contents deposited over the completed sewer at a distance sufficient to allow of the completion and inspection of a reasonable length. In addition to the saving of labour, this method has an advantage which may be of great value in that it minimises the obstruction of the roadway. On the other hand, the transportation of material over the heads of men working in the trench is an operation which calls for great care and every precaution.

All these appliances imply a considerable capital expenditure, and it is only on jobs where excavation of similar kind occurs in considerable quantity that their use will be remunerative. The greater diversity of conditions met with in an average sewerage undertaking in this country, as compared with American conditions, accounts for the fact that these appliances have been more developed there than here.

Tamping Machines.—These probably are more readily adaptable to British conditions than excavating machines. The " P. & H. Tamper," made by the Pawling & Harmischfeger Co., Milwaukee, and imported by Messrs. Gaston Limited, London, seems to have given satisfactory results here. It consists of a four-wheeled carriage which moves slowly along the trench, delivering a rapid succession of blows (about 42 per minute), from a ram weighing about 150 lb.

Interesting information is given in McDaniel's *Excavating Machinery* (McGraw-Hill Book Co., New York and London).

CHAPTER VII

Sewer pipes are made of stoneware, fireclay, and concrete. For some special cases iron or steel pipes are used. The two first named will be considered together.

Stoneware and Fireclay.—The difference between these is discussed in Part I (House Drainage, Chap. IV.) and a brief reference will serve here. Both are made by moulding and burning the plastic material, and the " spigot and socket " or " spigot and faucet " (Fig 24) is the standard shape in each case. In the south and west of England stoneware of high quality is produced, and the pipes are well shaped and smoothly and uniformly burned. In these districts " fireclay " is regarded as a very inferior material. In the north, and in Scotland, pipes made of fireclay are of high quality. They are frequently treated internally with a " slip " glaze, instead of the ordinary " salt " glaze, and this adds greatly to their smoothness and non-porosity. The author's experience has been that high-class fireclay pipes are slightly superior to high-class stoneware as regards strength and non-porosity, but (owing probably to the higher temperature required in burning) inferior in shape and uniformity. In fireclay pipes a greater amount of warping and twisting is tolerated than in stoneware pipes, and probably in practice a less severe standard in general appearance is demanded. Assuming, however, that the pipes in either case are good of their kind, the choice may safely be left to considerations of economy. Whichever is cheaper in the particular locality is the one that should be used.

Characteristics of a Good Pipe.—The material should be uniform and uniformly burnt, so that the pipe is thoroughly sound. This

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is usually judged by striking the pipe with a hammer, when a ringing sound should be given.

There should be no visible faults, such as kiln-cracks or blisters. The former are most commonly found at the plain or " spigot " end, and at the shoulder where the socket or " faucet " joins the body of the pipe. Blisters are chiefly to be looked for inside the pipe.

The shape should be good, the bore forming a true circle, and the whole pipe being straight.

The surface should be smooth and impervious. The quality of smoothness is of special value inside the pipe, on account of its influence on the flow of sewage.

The pipes should be free from any mechanical injury, such as not uncommonly results from railway transit.

Length.—Stoneware pipes of small diameter are usually two feet in net length (that is, exclusive of the socket) and those of larger diameter two feet six inches. Fireclay pipes (at least in Scotland) are three feet in net length, whatever may be the diameter.

Diameter.—Pipes are always described by their inside diameter, and 4, 5, 6, 9, 12, 15, 18, 21, and 24 inches may be regarded as stock sizes ; 7, 8, and 10 are also made, but are not so common. Pipes may be got up to 36 inches diameter but the largest sizes are seldom used. The lower limit of size is governed by the liability of small sewers to choke (see p. 21) while the upper limit is fixed by considerations of strength. The usual limit is given as 18 inches, but this is not a hard and fast rule. In favourable circumstances larger pipes might be used without hesitation, while in unfavourable circumstances special precautions would be necessary even with 18-inch pipes : this size therefore must be taken as an average limit, any departure from which requires special justification. The author has seen fireclay pipes of 24-inch diameter, which had been superseded by a new drainage system, taken out from under a busy roadway where they had stood for a number of years all the traffic of a town, and they did not show any sign of failure.

Thickness.—A common specification is that the thickness of the material is to be one-tenth of the diameter of the pipe. Some engineers are satisfied with one-twelfth, believing that the slightly reduced thickness is compensated by the more thorough burning and the generally higher quality of the thinner pipe. Thorough burning and sound material is more important than mass, and for most situations, and within the range of diameter of pipes generally used for sewer purposes, the thinner pipe is sufficient. Cases of course often occur when special reinforcement by concrete or otherwise is necessary (see below).

Strength of Pipes.—The strength of the pipes should be sufficient to resist (1) the weight of the superincumbent earth and any added load due to traffic, and (2) the impact of traffic. The former increases with the depth of the trench, though not in direct proportion to the depth : the latter is greatest in shallow trenches. In addition to these, which may be regarded as fair loads, a further load may come on the pipes through (1) subsidence of the bed on which the pipe was laid, or (2) negligent workmanship resulting in the pipe being suspended from socket to socket (see p. 84). Either of these may produce failure of pipes which are amply strong enough for their fair load, and the difficulty should be met otherwise than by using stronger pipes.

Most of the rules for strength of pipes are based on general experience, but a recent paper in the *Minutes of Proceedings of the Institution of Civil Engineers*, Vol. CXCII, p. 282 *et seq.*, by Mr. Edward Percy Currall, contains a record of numerous special experiments.

The general conclusions drawn from these are that pipes similar to those on which tests were made require no strengthening against the weight of the earth at all depths up to 20 feet in gravel, whatever their size. Against live load 9-inch pipes require strengthening when the cover is less than 2 or more than 18 feet : 12-inch and 15-inch pipes when less than 4 or greater than 11 : pipes of greater diameter always require strengthening against live load. In sand and loam all pipes at depths to 20 feet are safe against a dead load, but 9-inch pipes require strengthening against a live load when the cover is less

than 3 feet. 12-inch and 18-inch pipes require strengthening when the cover is less than 5 or greater than 20 : 18-inch pipes when less than 6 or greater than 14 : 21 and 24-inch pipes when less than 8 or greater than 12 ; and 27-inch pipes at all depths. In clay trenches pipes more than 18-inch diameter require strengthening against the dead load when the depth exceeds 14 feet, while against a live load all pipes at all depths require strengthening.

Comparing his results with the requirements of the Local Government Board, the author of the paper is of opinion that these requirements—that the pipes should be surrounded with concrete where in roads the depth of cover is less than four feet, or where in fields the depth of cover is less than three feet— are too stringent in the case of small pipes and insufficiently stringent in the case of large pipes.

In the above deductions a factor of safety of 2 has been taken. It is worth while to remark that many lines of sewer have been laid beyond the limits recommended without special strengthening, and that failure is certainly not inevitable. It is on the other hand probable that in many cases cracks have taken place, but not to such an extent as to render the pipes useless, and that therefore the failure which has actually taken place remains undiscovered.

When cracks do occur, they run either along the top and bottom or along the middle of the side, that is, on the vertical or the horizontal axis. One practical deduction from this is that when a pipe has a flaw insufficient to cause its rejection, the common practice of putting that flaw on the top is unwise. It is better that any part which is suspected of being weak should be put midway between the vertical and the horizontal axes.

British Standard Specification.—The specification for " Salt-glazed ware pipes " was issued in 1914. This refers to all pipes which are glazed " by the action of the fumes of volatilised common salt on the material of the pipes during the process of burning." It prescribes standard thicknesses, lengths, shape of sockets, etc., and the distinguishing brand implies that the pipes purport to have been made in conformity with the terms

of the specification. The ordinary brand does not imply that each individual pipe has been subjected to a hydraulic test, but it implies (among the other requirements) that the pipes are expected to stand a pressure of 20 lb. per square inch, under test conditions which are specified in detail. A further brand, which includes the word " tested " implies that the pipe on which it appears has actually stood the test.

It will be observed that the scope of this Standard Specification does not include all the classes of pipe which might be used for sewerage purposes, and that an engineer, in framing a specification, should only stipulate for compliance with this Standard Specification when he wishes clearly to exclude all classes other than those which it covers. In Scotland, for example, it would cut off all the ordinary sources of supply, and the specified lengths exclude the Scottish length (3 feet) from the smaller sizes, and only give it as an option in the larger sizes. It is also inapplicable to the " slip glaze " which is often applied with excellent results to fireclay pipes (see p. 73). It may be assumed that specifications dealing with such pipes will follow in due course.

Pipe Jointing.—The ordinary pipe is jointed with cement mortar, with or without yarn. The plain or spigot end of the one pipe is introduced into the socket or faucet end of the pipe already laid, and the annular space is filled with cement mortar, Fig. 24 : but in order to secure proper centring of the pipe, and at the same time to ensure that no mortar will pass into the bore of the pipe, it is a common custom to fix a couple of turns of yarn round the plain end, and to caulk these hard into the bottom

Fig. 24.—Spigot and Socket Joint.

of the joint. The yarn is either tarred, or soaked in cement " grout " (that is, cement mixed with so much water that it is practically liquid) in order to hinder or prevent its decay. It is an open question whether yarn is desirable : the advantages are undoubted, but the use of a perishable material introduces

an element of weakness. After the decay of the yarn there is left a space filled with putrid matter, which prevents thorough cleanness. Effective centring may be got by using mortar sufficiently stiff (putting in some hard material such as a scrap

FIG. 25.—Wooden Scraper.   FIG. 26.—Rubber Disc Scraper.

FIG. 27.—Badger.

of broken pipe is not to be recommended), and by the use of a scraper any intruding cement can be removed. The scraper may be a plain wooden disc or half-disc (Fig. 25) : a rubber disc mounted on wood with projecting edges (Fig. 26), carried on a wooden shaft in either case : or the " badger " of Mr. F. C. Lynde, consisting of two discs at a little distance with a spring
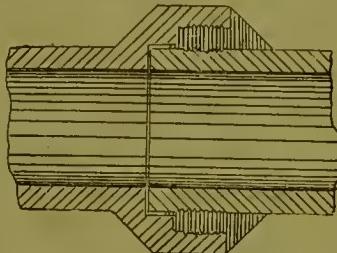
FIG. 28.—Hutchison Joint.   FIG. 29.—Fitzpatrick Joint.
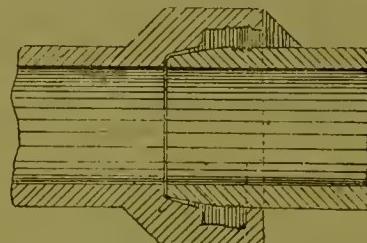
connection and each faced with rubber rings, which is drawn through the pipe (Fig. 27). Even a bag stuffed with straw and drawn through the pipe after the joint is made, is sometimes

FIG. 30.—Mansfield Joint.

used. The author is disposed to attach more importance to the care used by the workman than to the tool.
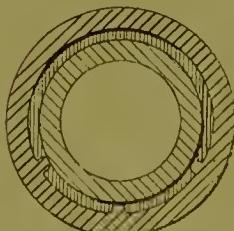
On the whole, the balance of advantage seems slightly against the use of yarn. The joints shown in Figs. 28, 29, and 30, are designed to give effective centring without it.

Cement mortar ought invariably to be made of Portland cement, and its quality is of some consequence. On a sewerage work of any size there should be no difficulty in arranging that the cement is properly tested, and in particular that it is efficiently aerated, but in small jobs (referred to in the companion volume on House Drainage, Chapter IV) there is difficulty in securing that the cement is up to the standard. For ordinary joints the cement is mixed with an equal bulk of sand, and the amount of water used should be such that the mortar is a fairly firm paste. It must be well pressed into the joints, and should not be finished flush but bevelled. Great care must be taken to avoid injury to the joints, either when they are lying exposed, or in the process of refilling the trench (see p. 64).

"Roman" cement is occasionally used when very quick setting is desired, but it is not nearly so good as Portland, and its use is seldom justifiable for such work as this. For house drainage it is seldom necessary or desirable to use pipes with joints specially designed for use in bad ground, for the reason that when such precautions are required it is better to use cast-iron pipes. In sewerage work this does not apply, as it often happens that, although ordinary joints are insufficient, a form of construction much cheaper than iron piping may serve the purpose. In house drainage it is of great importance that the pipes should not permit the *escape* of liquid or of gas, and tests are applied to ensure that everything which enters the pipe will be retained : it is in the case of sewers equally important to secure that nothing will *enter* the pipes from the adjoining soil. The function of sewers is to deliver the sewage at purification works, and the capacity of these works is carefully adjusted to the expected volume of sewage. If the volume is augmented by an indefinite quantity of subsoil water, the purification processes may be seriously hampered. Where this danger is to be apprehended, it is sometimes stipulated that the pipe line must not show a greater flow of subsoil water than a fixed quantity per mile, and ordinary joints made in a wet trench are not sufficient, or at best require so many precautions that it is usually better to use special joints.

These joints depend either on Portland cement or on some

plastic composition (usually of a bituminous nature) or on a combination. The cement should if possible be applied in the form of mortar, but this is often impossible, and it is then applied in
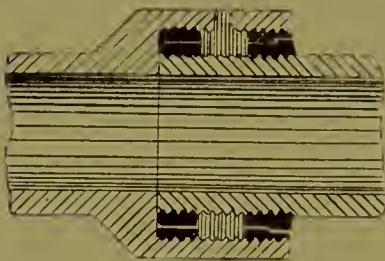
FIG. 31.—Joint made with Cement Grout.
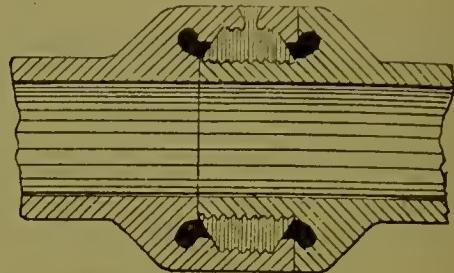
FIG. 32.—Joint made with Cement Grout.

the form of " grout "—that is, the cement is mixed with so much water that it becomes liquid and can be poured into the joint. " Grout " joints are made with an annular cavity, formed either of temporary or permanent materials, into which the
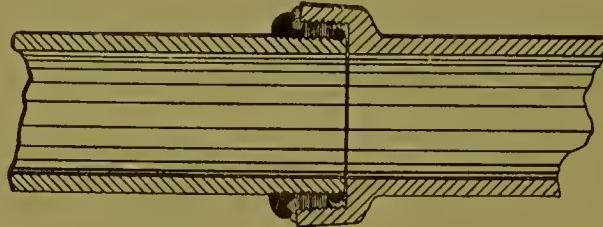
FIG. 33.—Composition and Grout Joint.

liquid is poured. Figs. 31, 32, 33 and 34 illustrate such joints, among well-known types of which may be mentioned those of Ames-Crosta, Archer, Doulton, Hassall, Jennings, Stanford, Sykes, and Tyndale.
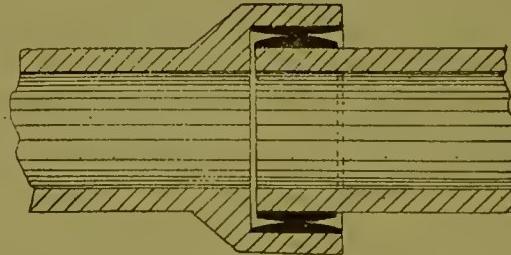
FIG. 34.—Composition Joint.

Testing Pipe Sewers.—It is easy to specify that sewers are to stand a test : it is not always easy to apply this test. The difficulty does not arise when a long stretch of new sewer, without connections, has to be laid : but it is a very practical one when a sewer is laid in streets among houses from which connections have to be made. In such cases, looking among other things to the requirements of traffic, it is often out of the question to incur the delay which testing would involve. All that can be done is to depend on supervision.

In new sewers tests of various kinds may be applied. The most common is that of internal water pressure, applied in exactly the same way as to house drains. The lower end of the pipe is plugged so as to be watertight, and the length to be tested is filled with water. If it remains full after a sufficient lapse of time, it is accepted as tight. The pressure is not uniform throughout the sewer, and it is necessary to limit the vertical height on the section under test so that on the one hand no part shall be exposed to an unreasonable pressure, and on the other hand no part will escape with an insufficient pressure. The difficulty is not so great as in drain testing, as the gradient is less and there are no vertical pipes ; but it must not be overlooked. One practical difficulty is that there is not always at hand a ready supply of water to fill the pipe, which in the case of a large pipe may be a substantial quantity.

A fair range of pressure would be obtained by specifying that it should not at any point exceed six feet of water nor be less than two. The pipes of course could stand much more than that. (See Part I, House Drainage, Appendix, Note A.)

Another method of testing is to allow the trench to fill with water to its natural level—either alone or in conjunction with the earth filling—and to see whether any water issues from the lower end of the section under test. In the case of a pipe through wet ground this is at once the simplest and the most useful test. It does not put upon the drain any burden beyond what it will be called upon to take in actual working : the only objection indeed is that it may be impossible to reach the worst working conditions at the time of test. The test is likely to take place under conditions more lenient than those of ordinary work, and it is usual

to make fairly stringent stipulations as to the amount of subsoil
water per mile of sewer which will be accepted.

Keeping of Gradient.—Now that sewers are invariably laid in
straight lines from point to point, the method of setting each
individual pipe by means of spirit level and straight edge is
almost entirely superseded by the method of " boning " or
" sight rods." The work is set out by means of a surveyor's
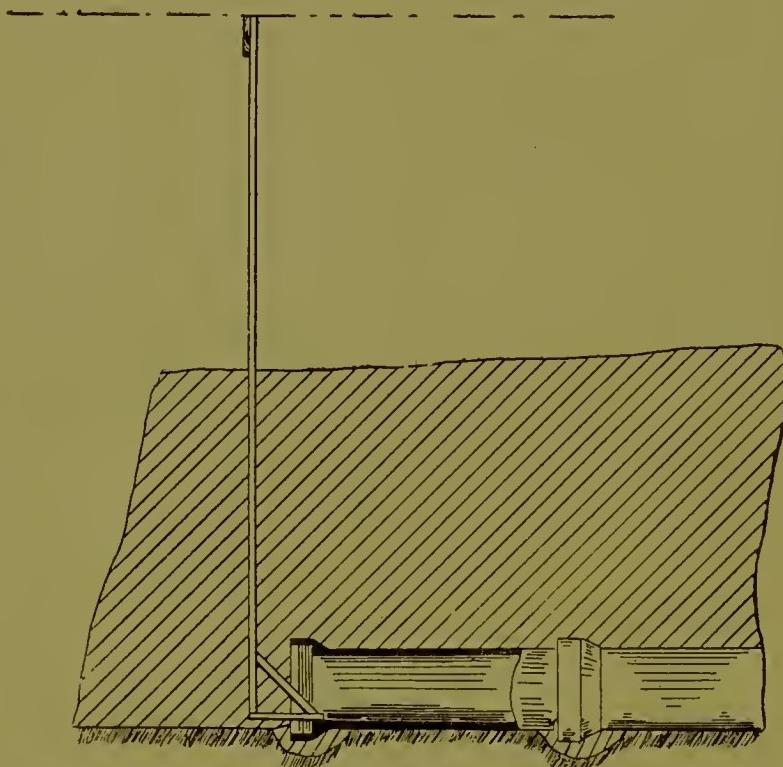
Fig. 35.—Boning Rod.

level, pegs are put in at convenient places—usually at the man-
holes—and the invert level below each of these pegs is calculated
and given to the foreman of the pipe-laying squad. He sets up
his " profile " at each end of the section, the profile consisting of
a horizontal board carried on uprights and spanning the trench.
The upper edge of this board is the " sight," and is set carefully
level at a determined height above the pipe invert. The pipe-
laying proceeds between two of these profiles, and the pipe-layer

has a portable cross board (Fig. 35). This is carried on an upright shaft, provided at its lower end with a shoe which enters the pipe, and the length from the base of the shoe to the upper edge of the cross board is the same as that for which the profiles are set.

Suppose the section is 100 yards long, and the gradient 1 in 150. The fall on that section will thus be 2 feet, and the lower
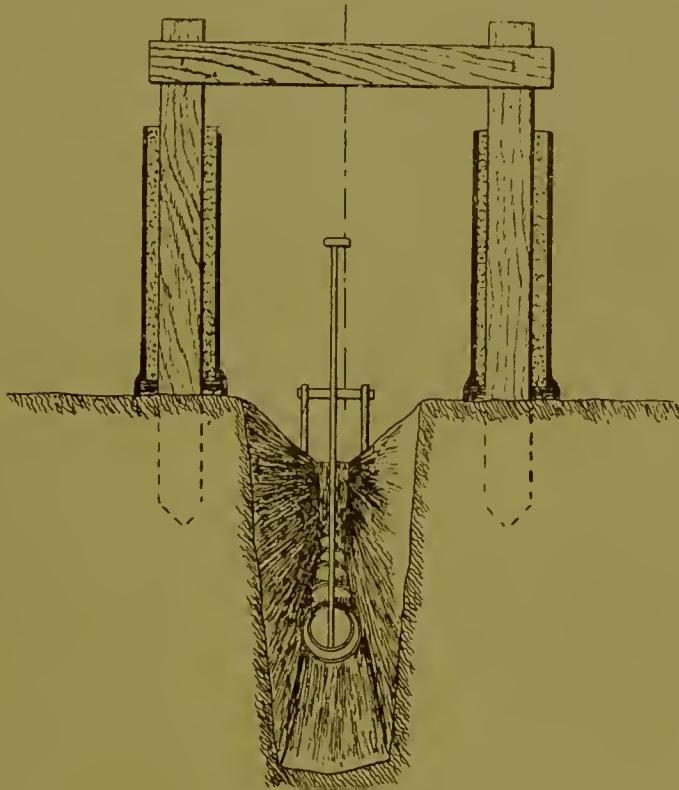
FIG. 36.—Boning Rod and Profiles.

profile will have its sighting edge 2 feet lower than that of the upper one, a straight line between the two being parallel with the required invert line of the pipes. The distance between these two parallel lines is determined by the depth of cutting and consequent convenience of working, 9 feet is common when the trenches are of ord'nary depth, but it may be greater or it may be considerably less. Whatever the distance may be, the rod used in setting the pipes must have the same distance between shoe and sighting edge.

It is desirable that the distance should be as little as is consistent with convenient working, as with a long rod there is the chance of appreciable error through the rod not being held upright. Every surveyor knows how this may occur with the levelling staff, and it is not less likely with the sighting rod. But any divergence at right angles to the pipe line should be readily noticed by the man who is sighting, and if a fairly long and clean shoe is fixed on the bottom of the rod, and if this is allowed to rest firmly on the invert of the pipe already laid, the error should be slight. The distance will usually be measured at right angles to the pipe invert and not in a true vertical line, and it may be necessary to allow for this. With ordinary sewer gradients this will not cause any perceptible difference, and in any case it is the same throughout.

The method of working is as follows : Suppose the pipe line to be so far laid : the pipe layer is proceeding to lay another pipe (Fig. 36). The diggers have prepared the trench almost to the required level, and before lowering the pipe into the trench a "socket-hole" is cut. The pipe is set in place, with its spigot in the socket of the pipe already laid, and its socket in the newly cut hole. The pipe-layer sets up the rod with its shoe projecting into and resting on the invert of the pipe which is being laid, and the man at the profile tells him how much the pipe must be lowered. The bottom of the trench is cleared to as nearly as possible the required amount, and the rod again tried. After one or two trials the exact level should be got, the pipe is shouldered up and made secure, and the joint is made. It is important that the shouldering and packing should be done before jointing, as the subsequent doing of these things will disturb and break the joint.

Socket or Faucet-holes.—The pipe should rest on its "barrel" and not on the socket or "faucet," therefore holes are cut at each socket (Fig. 37). If this were not done, each pipe would form a girder supported at its ends, and carrying the load of superincumbent earth. The distance between the points of support would be practically the length of the pipe. But when socket holes are cut the greater part of the length of each pipe

is supported, the unsupported part being only that over the hole. The difference is very great, and this precaution should never be neglected. The hole has the further advantage that it gives convenient space for making the joint.

Setting Pipes by Spirit Level.—It is occasionally necessary to do this, but it should be avoided if possible. The method of
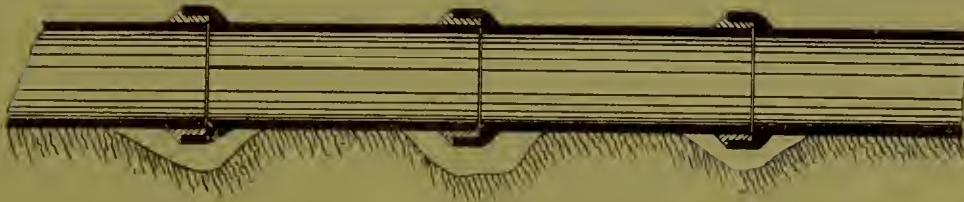
Fig. 37.—Socket Holes.

working is to have a spirit level and a straight-edge so arranged that the upper edge is horizontal when the lower edge rests on the pipe at the proper gradient. There are many ways of doing this. " Gradient-rules " (Fig. 38) are made, in which the straight-edge consists of two hinged bars, one to rest on the pipe and the other to carry the spirit level, with a screw adjustment for setting off any required angle. A much simpler implement is an ordinary parallel straight-

Fig. 38.—Gradient Rule.

edge, with a screw nail projecting to the required distance, any alteration of gradient being made by screwing the nail in or out. Loose blocks of the required height are sometimes used ; and sometimes when there is a long stretch of uniform gradient the straight-edge is cut to suit.

There are several objections to this method of working. The pipes are by no means uniform, and the difference in shape between two adjoining pipes may be more than the fall. This is more serious with fireclay than with stoneware pipes, but it may be a serious matter with either on a flat gradient. In soft ground the pipes may sink after being levelled, and this may
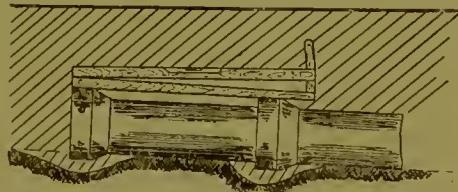
completely upset the gradient of a considerable length of pipes. A careless workman has been seen using the straight-edge wrong way about, and steadily going on a reversed gradient.

Speaking generally, the objection is that as each pipe depends on that immediately preceding, any error is carried on uncorrected and the accumulated error may be a serious matter. By the method of boning rods each pipe is levelled by an independent reference to the line of sight, and any error is corrected automatically.

Concrete Pipes.—These have not come into very extensive use, but they have been successfully used, especially in large sizes. They have the advantage that they can be manufactured
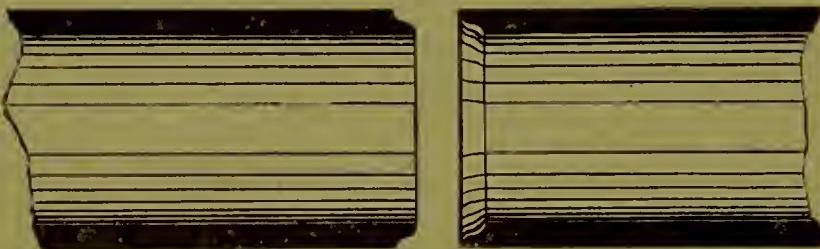
Fig. 39.—Concrete Pipes.

on the spot, or at least near the place where they are to be used, and as the carriage of stoneware or fireclay pipes is a very serious item in their cost, the use of concrete tubes allows a considerable saving. In order that the concrete may be sufficiently hard, the tubes must be moulded and stored for a considerable time.

When good aggregate can be readily procured, and when the tubes are required in sufficient quantity, there may be a distinct saving in putting down the plant required for their manufacture. They have one decided advantage : they can be made of any required thickness, and so can be used of a diameter greater than would be judicious in the case of a material which has to be burnt, and where the permissible thickness is thus limited.

The usual joint is of the " ogee " form (Fig. 39) and is made with cement mortar, as in Fig. 40.

A further development, which may not have yet gone so far

as it ultimately will, is the use of reinforced concrete for pipes. Such tubes have been used both for water and for sewerage purposes, and while difficulties have been met in their use, it is not improbable that they may be overcome. Their use in this country had scarcely got beyond the introductory stages.

Cast Iron Pipes.—These are used only under exceptional conditions, such as :—

(a) Where the flow is under pressure.
(b) Where the gradient and therefore the velocity is excessive.

Elevation.   Cross Section.
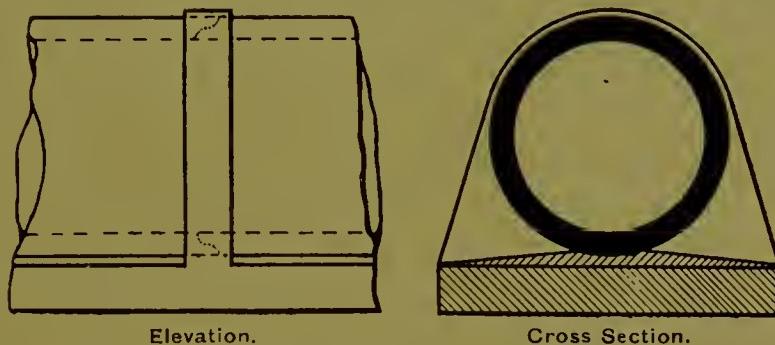
Fig. 40.—Concrete Pipes Jointed.

(c) Where the traffic conditions require extra strength : for example, in crossing under a railway.
(d) Where the ground is waterlogged or otherwise bad.

For sewer purposes iron is much more durable than for water supply purposes. Except in those places where the soil contains substances which attack the outside of the pipe, corrosion is not a serious question. Sewage does not act on the inside of the pipes in the way that pure water does, and any deposit is quite different from the incrustation which is familiar to water engineers. Under ordinary conditions the pipe is efficiently protected by the usual coating of " Smith's Solution," but when it passes through ground which is chemically active with regard to iron it may be necessary to protect it—by a concrete sheath for example— from direct contact with the ground. Some manufacturing effluents would have an injurious effect, but the ordinary powers

of Local Authorities are sufficient to ensure that such effluents are rendered harmless before entering the sewers.

Iron pipes are used of very much the same weight as for water supply purposes, the makers' standards being adopted. It is usually safe, however, to use the lightest of the various gauges
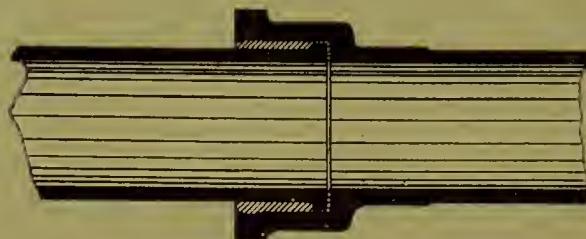
FIG. 41.—Joint on Cast Iron Pipe.

given, as the pressure of sewage is seldom great, and all that is wanted is sufficient strength to resist the weight of traffic. The jointing is exactly like the jointing of water mains, molten lead, ribbon lead, lead wool, or the like, being caulked into the

FIG. 42.—Expansion Joint.

joint (Fig. 41). Perhaps it happens more frequently than in water work that the use of molten lead is awkward, and therefore the substitute materials are more likely to be useful. Lead wool and ribbon lead are merely the metal shredded (by different processes) into fine strips. These are packed into the joint like so much oakum, and by caulking become practically solid. As they require no heating, they are useful in wet ground. For some purposes bolted joints may be used, or special joints which give greater flexibility, such as Jones's expansion joint (Fig. 42), introduced by Messrs. Jones & Attwood, of Stourbridge.

Steel Tubes.—These are used for reasons similar to those which indicate the use of cast iron. They are better than cast iron when they are subject to the shock of traffic, or where flexibility
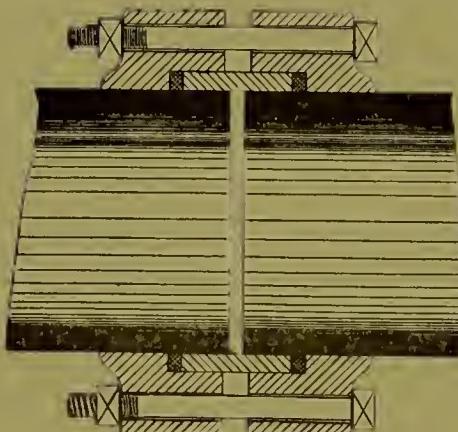
is an advantage. They are made in long lengths, up to 30 or 40 feet being procurable and 18 or 20 feet being common, and the reduced number of joints gives them a further advantage.

The tubes are usually only about half the thickness of cast iron pipes, and when there is any prospect of progressive corrosion their durability is of course correspondingly lessened. But as in the case of iron, the chance of internal corrosion is not great ; while external corrosion is guarded against by the same method of coating. This coating is usually supplemented by a covering of " Hessian " (a coarse variety of canvas) saturated with the same composition.

Steel tubes may either be riveted, welded, or " weldless." Welded tubes should be " lapwelded " and not " buttwelded," but weldless are probably the most satisfactory, especially for

FIG. 43.—Insertion Joint on Steel Pipe.

underground work where corrosion may be an important factor. The weldless tubes are drawn direct into tube form from the steel billet, while the riveted and welded tubes are made from plate steel. It is seldom that actual strength is of much direct consequence, as a very thin tube will easily withstand any internal pressure, while the risk of fracture, which is the serious one with brittle materials, is altogether absent. The only effect of heavy loading would be to produce deformation in the tube, and this is not likely in any ordinary conditions.

The steel tubes are fitted with sockets similar to those of cast-iron pipes, and the jointing is done in the same way (Fig. 43).

Access to Iron or Steel Pipes.—It is usual to have an ordinary manhole at each end of any stretch of sewer, whatever may be the material of which it is constructed. In that case access is got to the end of the section in the usual way (see Chapter XI). It may happen, however, that on a long pipe working under pressure

it is necessary to have access to parts which are not accessible by ordinary manholes, and it is then necessary to provide " hatchbox " openings (Fig. 44). On the inverted syphon shown
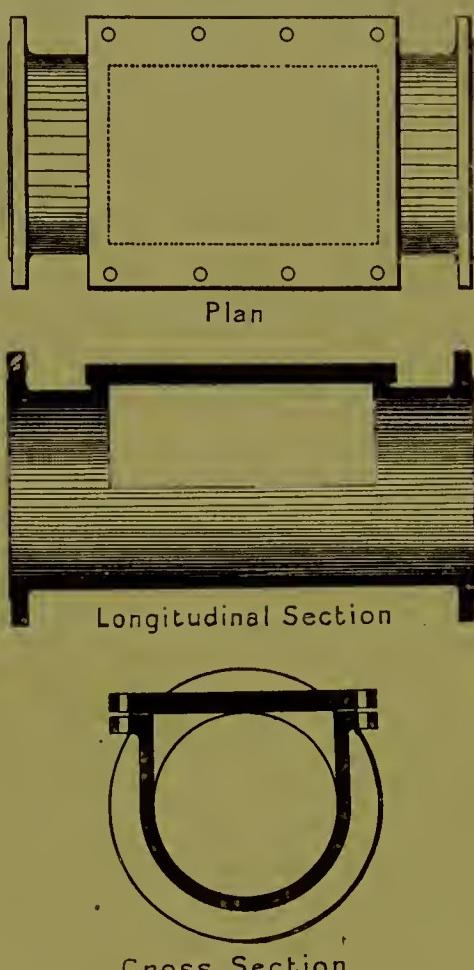
in Fig. 96 a number of these openings are shown. They are only for use in the event of a stoppage taking place, and the tube would of course be emptied as far as possible before the bolts of the hatch-box cover were slackened. The total pressure which these hatchboxes will be called on to resist is small compared with the pressure which occurs in the case of water mains.

Another precaution against obstruction, which was adopted in the same case, was to have the iron pipes made with bolted joints and gun-metal bolts. In the event of any obstruction taking place not readily accessible from a hatchbox, it would be practicable to take out any length of pipe, and to replace it without injury.

Plan

Longitudinal Section

Cross Section

Fig. 44.—Hatchbox.

The joint illustrated in Fig. 42 gives great facility for access, but at the cost of using a somewhat perishable material in the joint. In a pipe line of trifling depth and in open ground the use of this joint may supersede the need for hatchboxes, as a short length of pipe could be taken out quite as easily as a hatchbox could be opened.

CHAPTER VIII

THE CONSTRUCTION OF BUILT SEWERS

When sewers larger than eighteen to twenty-four inches in diameter are required, the ordinary pipe sewer is unsuitable. The choice then lies between concrete tubes (discussed in the last chapter) and built sewers. Built sewers are constructed of brick, with or without " invert blocks " ; or of concrete *in situ*.

Invert Blocks.—These are foundation blocks of stoneware or fireclay, shaped so as to give a flat bearing on the soil, a properly curved invert for the sewer, and a surface from which the brick . building may start (Fig. 45). They are made hollow so as to save weight and to ensure better burning, and it has sometimes been suggested that the opening through these blocks might be utilised for under-drainage, a passage for clean subsoil water being thus provided in the structure of the sewer. This is not now considered desirable : under-drainage of this sort is apt to undermine the sewer, as the entering water brings in also particles of sand and the like. It is the practice to plug these holes with concrete before the blocks are laid, thereby adding to the weight and solidity of the blocks and obliterating the through passage. The blocks are made to suit the size, shape, and thickness of the sewer.

Fig. 45.—Invert Block.

Shape.—For sewers of moderate size the egg-shaped sewer is almost universal. The lower limit of size is that at which pipes become possible, which means that the smallest egg-shaped sewer is about 2 ft. 3 in. by 1 ft. 6 in. ; the upper limit is less definite, but may be taken as about 3 ft. 6 in. by 2 ft. 4 in.

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The advantage of the egg-shape is that it adapts itself to the requirements of a varying flow. For such a flow a circular sewer is unsatisfactory, for if the flow is very small it gives a very large wetted perimeter in proportion to the sectional area of the

FIG. 46.—Egg-shaped Sewer.

liquid: hence the hydraulic mean depth is small. The egg-shaped sewer provides an invert of small radius, so that a small flow is confined in a small channel: while the upper part is large and gives room for a large flow.

Figs. 46 and 47 illustrate two well-known shapes. The height is in each case $1\frac{1}{2}$ times the breadth, but while in the former the radius of the invert is half that of the upper part, in the latter it is only one-quarter. Hence the latter is more suitable in the case of extreme fluctuations of flow. Numerous other sections have been designed, but these shown are sufficiently typical.

It is to be observed that the strength of the section is diminished as the shape becomes flatter. The straight-sided or "peg-top" section (Fig. 48) has advantages as regards flow, but loses the strength due to the arch shape of the sides, and is not often employed.

There is, however, no shape which is so strong, and which gives so much

FIG. 47.—Egg-shaped Sewer.

sectional area in proportion to the perimeter, as the circular. Unless there is some specific and important reason for departing from it, the circular shape is employed in built as in pipe sewers. The reason for departing from it is usually the one just mentioned—to meet the requirements of a variable flow, and the extent of variation should always be considered before deciding on the shape.

A circular sewer has the same hydraulic mean depth when it is either full or half-full. If, therefore, the maximum fluctuation
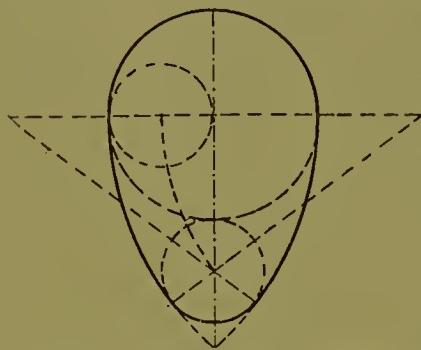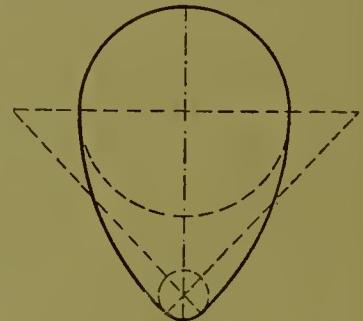
expected do not materially exceed the proportion of two to one,
there is no reason for departing from the circular form.   In
ordinary street sewers, where the drainage is on the " combined "
system, this proportion is often largely ex-
ceeded, and the flow is sometimes very small.
In such circumstances it is important to ensure
that the small flow will be confined in a small
channel.   In large main sewers, on the other
hand, the minimum flow is always a substantial
quantity, and the maximum flow is restricted
by the use of storm overflows.   In such circum-
stances, although the variations may exceed
considerably the two to one proportion, and
although therefore in theory there would be an

Fig. 48.—Peg-top
Sewer.

advantage in the egg-shape, the practical advantages of the
circular section are of more consequence, and thus the upper
limit of size of egg-shaped sewers is determined.

Bricks.—The bricks used in building the upper semicircle of
the sewer need only to be good sound bricks of ordinary quality,
their function being to form a cover and resist the pressure of
the earth.   But the bricks which form the invert of the sewer
require special attention.   They have to resist the eroding action
of the sewage and of the solid particles of grit which are carried
along with it, and they must not be acted on by the constituents
of sewage.   These requirements do not apply to the outer ring
of brickwork but only to the inner surface on which the sewage
will flow.   The best bricks for the purpose of this construction
are " blue bricks," the typical examples being the Staffordshire
blue bricks : glazed fireclay bricks are also quite satisfactory.
    All the bricks—of whatever kind—must be made of a taper
shape to suit the curvature of the sewer, so that the joints will
be close both at back and front.   All jointing is done with Port-
land cement mortar, the proportion of cement and sand being
usually equal parts by measure.

Building.—The building must be done to template, and the
arch is built on a wooden centre   When one ring of brickwork
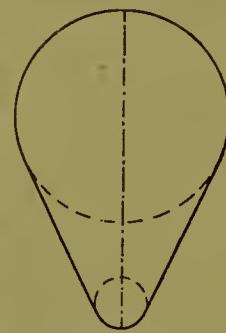
is sufficient, the building is exactly like that of a wall of the same thickness : but when more than one ring is needed, the method is different, inasmuch as no bonding is used between the two rings. The reason is that the primary object is to form a watertight channel, and headers would form joints right through the whole thickness. Besides, there is no possibility of stress which would tend to separate the two or more layers of brick, the pressure always tends to press the layers more firmly together. In some cases (as recommended by Baldwin Latham) a "collar joint" is introduced between the two rings of brick, this being a complete sheet of cement mortar, say an inch in thickness, between the two rings (Fig. 49). The object of this is to make the tightness of the compound structure more certain. The ordinary joints in sewer building should all be thin, not more than a quarter inch thick, and should be "key drawn" after being made. This means that the point of a tool is drawn carefully along the edge of the joint when the cement has partially set, and this smoothing of the surface is of some consequence in making tight work, besides giving a smoother flowing surface.

Fig. 49.—Collar Joint.

It has been pointed out that bricks of the quality required for sewer work are not so good for jointing, as the mortar does not adhere to them in the same way as it does to bricks with a rougher surface. In the manufacture of invert blocks, it is usual to roughen the surfaces from which the brickwork is to spring, and to protect it as far as possible from the process of glazing. But as the pressure is inward and not outward, the tenacity of the joints is of less consequence, and while it is desirable to have the bedding surfaces of the bricks comparatively rough, it is much more important that the exposed surface should be smooth
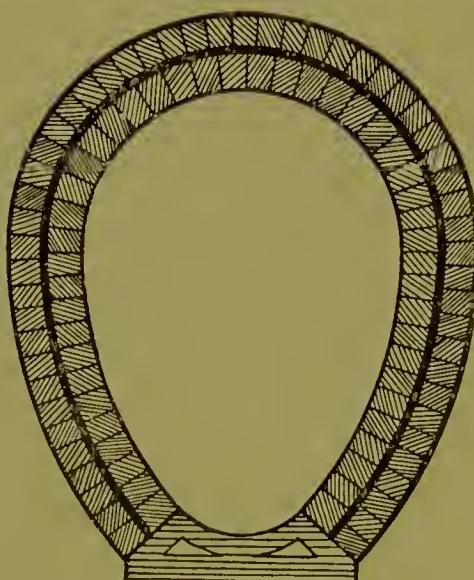
and clean. Of course cases occur sometimes when sewers are carried partly above the surface of the ground, and when therefore an internal or bursting pressure is possible : but these are exceptional, and even then the pressure to be resisted is usually very small. Such cases must be dealt with in exceptional ways.

Thickness of Brickwork.—The rule given by Baldwin Latham is a simple one : if the depth of cutting does not exceed 20 feet, if the ground is good, and if the greatest internal dimension of the sewer does not exceed 3 feet, a sewer with curved walls does not need more than one ring of $4\frac{1}{2}$-inch brickwork. If from 3 to 6 feet in size two rings would be used, and greater diameters in proportion. The principle is the same as that of an arch, loaded with the weight of superincumbent earth ; and in any unusual circumstances, such as extreme depth or size, or unsatisfactory nature of soil, the required thickness should be calculated on this basis. The paper by Mr.

Fig. 50.—Conerete Hood.

Currall (*Proc. Inst. C.E.*, Vol. CXCII, p. 282), quoted in the last chapter, contains very interesting data as to the proportion of load transmitted at different depths and with different materials, and may with advantage be read in this connection.

Concrete Backing or Capping.—Instead of increasing the thickness of the brickwork, a concrete " hood " is sometimes employed (Fig. 50). This is chiefly of service when the danger apprehended is the weight of material or impact of traffic on the top of the sewer : it gives the extra strength only where it is required, at a less cost than would be incurred were the whole sewer to be strengthened by an extra ring of brickwork.

Sewer Junctions.—Junctions of pipe sewers are made by special branch pieces, moulded to suitable sizes and angles. Junctions
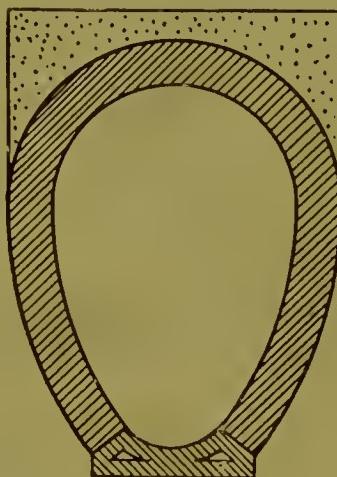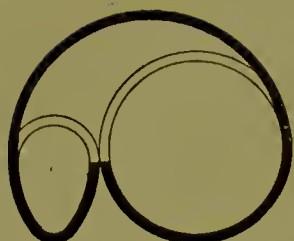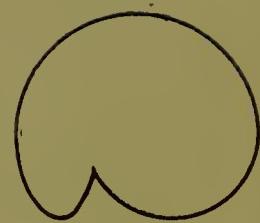
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Section D. D.
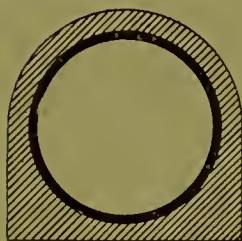
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Section A.A.
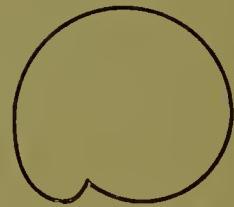
Section E. E.

Longitudinal Section H. H.
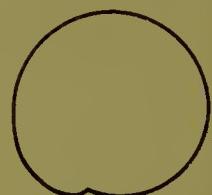
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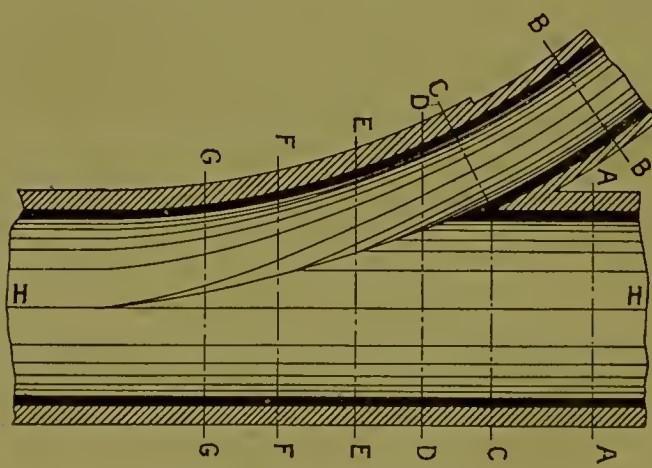
Section G.G.

Sectional Plan
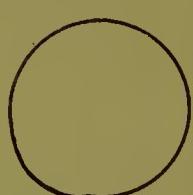
FIG. 51.—Built Sewer Junction.

on brick sewers are individually designed and set out, and may involve some rather elaborate work. Such a junction is shown in Fig. 51.

CONCRETE SEWERS

Rock Trenches.—When sewers are constructed in trenches which are sufficiently hard to need no support, an economical form of construction may be to use merely a lining and an arch (Fig. 52). The rock itself forms the bottom and sides, the concrete lining being required only to give smoothness and uniformity.

Soft Foundations.—On the other hand, when the bottom is very soft, and where therefore it is important to have a broad base to carry the weight of the sewer, concrete may again be useful. In some cases a timber platform on a piled foundation has been put down, and on this the concrete sewer has been constructed (Fig. 53).
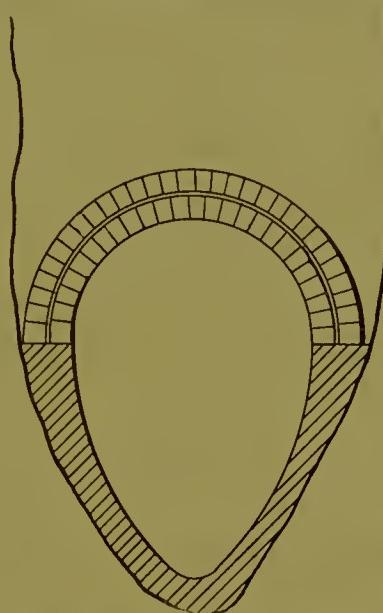
FIG. 52.—Sewer in Rock.

General.—The advantage of concrete is more marked in these two extreme cases than in the intermediate case, when the ground is sufficiently firm to sustain an ordinary built sewer, but not so hard as to form part of the sewer itself. In the intermediate case the cost of timbering to form the lower part of the sewer of concrete of a suitable thickness is considerable, and concrete is economically at its best when a base of considerable breadth is required.

Reinforced Concrete Sewers.—In designing a large sewer, the choice between brickwork, mass concrete, and reinforced concrete will naturally be determined by considerations of relative cost. Reinforced concrete is thinner and lighter than mass

concrete to give the same strength, and thus costs less for cement and aggregate : against which is to be set the cost of the steel reinforcement and the extra labour in constructing the sewer.
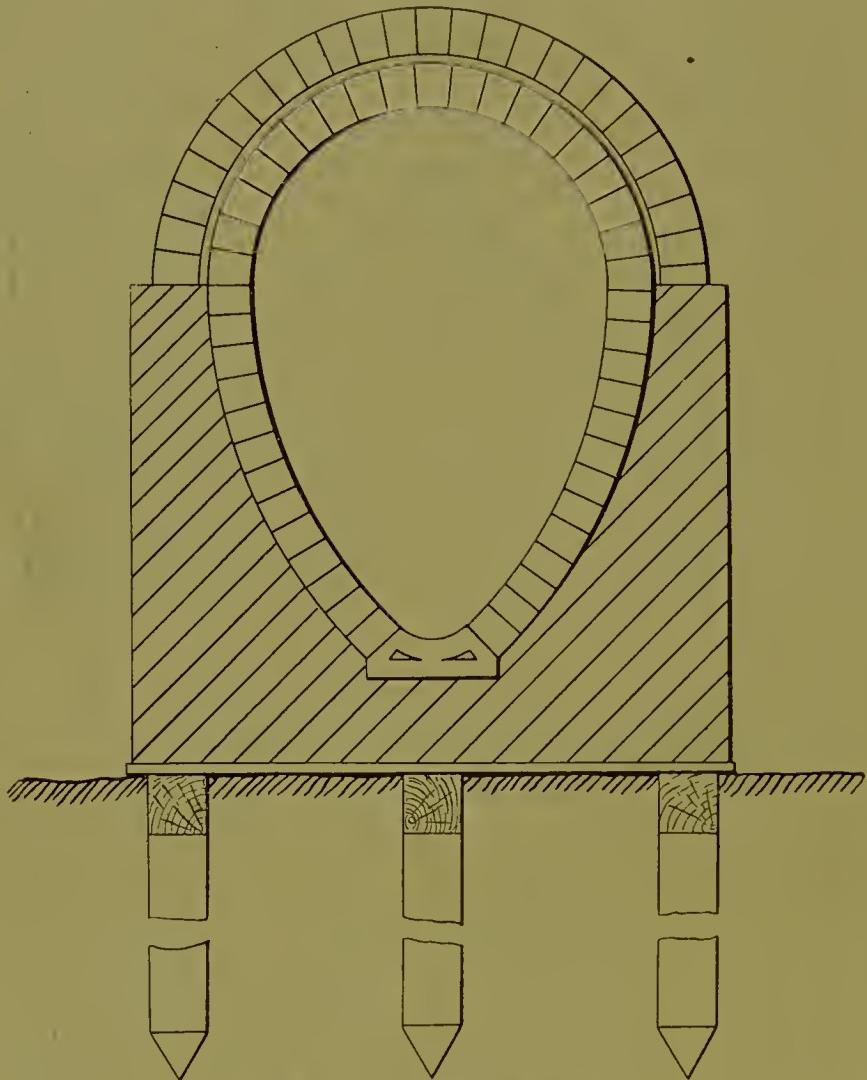
FIG. 53.—Sewer on Piles.

Mr. Ernest Romney Matthews, in a paper printed in the *Proceedings of the Institution of Civil Engineers* (Vol. CLXVII), deals fully with reinforced concrete sewers, and gives particulars of plain and reinforced concrete sewers in the same system. The reinforcement in the latter case consisted of transverse bars $1\frac{3}{8}$ by $\frac{1}{2}$ inch in section, spaced 2 feet apart centre to centre ; and longitudinal

rods $\frac{3}{16}$ inch in diameter. The concrete per lineal foot for an 8-foot sewer was 1·16 cubic yard without, and 0·63 cubic yard with the reinforcement, which required 17·1 lbs. of steel per lineal foot. In this particular case the reinforced concrete was the more economical, the overhead cost including excavation and filling being £1 5s. 8d. per lineal foot against £1 8s. 2d. for the plain concrete. It is scarcely necessary to add that these costs were " pre-war," but it may usefully be remembered that the present very high cost of timber has an important bearing on relative costs.

CHAPTER IX

SEA OUTFALL SEWERS

THE design of a sea outfall sewer involves two different considerations : (1) whether, and if so where, the sewage can be discharged without being offensive ; and (2) how will the flow of the discharging sewer be affected by the presence of the water of the sea, and especially by its varying level due to the rise and fall of the tide.

There are numerous details which call for consideration in any definite scheme, and the subject of sea outfall sewers is one which might occupy and has occupied complete treatises. The general principle only can be referred to in a single chapter.

PLACE AND TIME OF DISCHARGE

Tidal Currents.—A careful investigation of these is the first essential in designing a satisfactory sea outfall. The investigation must extend over not less than a complete range of tides, and requires observation of floats both surface and submerged. The travel of a surface float, even apart from any wind action, may be very different from that of, say, a six or eight-foot rod floating vertically. Sewage matters include not only those which sink gradually to the bottom but also those which float, and the one may be quite as offensive as the other. The discharge of crude sewage into the sea is only justified when the tidal currents are such that all its constituents will be carried away and disintegrated in the open water.

The required investigations are tedious. Observers in boats are needed, and the method is to launch suitable floats at various stages of the tide, and to keep note of their movements until they (1) have gone well away from the shore ; (2) have been

thrown ashore, or (3) have been in the water for such a time (say, 48 hours) that sewage matters in the same circumstances would have become indistinguishable and therefore inoffensive.

Deep floats are conveniently made of wood, say six to nine feet long and three inches square (Fig. 54). One end is weighted so that the stick will remain upright in the water, and the other is painted some conspicuous colour. Different colours are
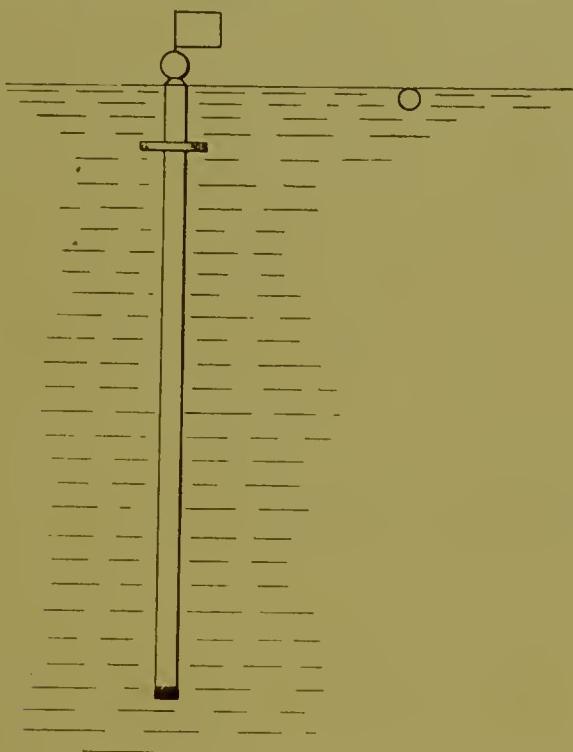

FIG. 54.—Deep and Shallow Floats

used to distinguish the place and the time of starting. To facilitate observation a small flag made of brightly painted tin or zinc may be fixed to the top by a wire, but the flag should be free on its wire so that it may not catch the wind. The ballast weight is so adjusted that the top of the float is just above the water surface. Such a float is carried by the movement of the body of the water and not merely by surface flow. To observe the surface flow extemporised floats such as oranges or slices of turnip, which are only slightly lighter than sea-water, may be used. The observers who are following the deep floats will probably

find that they cannot keep both in view, as they will take different courses, but they can throw out a succession of these small objects and note their progress so long as they keep within range. Alternatively, larger surface floats made of wood ballasted so as to float just awash may be followed by independent observers.

Purpose of Investigation.—The purpose of this investigation is to ascertain whether it is possible to discharge sewage at a given place or places, with a reasonable certainty that it will be carried off by the currents and not thrown back on the beach. If a continuous discharge is contemplated, floats must be started at various stages of flowing and ebbing tide, both spring and neap. If it is evident that the discharge must only be on the ebb, then the observations are made by starting floats at various hours of the ebb, to determine the limits between which the discharge may safely take place. Further, there may be various places which from general considerations seem well suited for the construction of an outfall sewer, and each of these should be tested by making it the starting-point of the floats. The preliminary investigations may suggest some other place, not at first sight apparently suitable, and that also should be tested.

Time of Observations.—The required observations are therefore a matter of weeks at least, and as much of the work is very dependent on the weather it is evident that the preparation of a sewage scheme involving work of this sort is not a thing that can be done hurriedly. It is desirable that a summer season should be available for making and working out the required observations. Observations on anything but a comprehensive and definite system are at best useless, and may be seriously misleading, and an engineer engaged on this sort of work will be well-advised to avoid any observations other than those on which he can really depend. Valuable information may be got from those whose work brings them into contact with the tidal currents, such as boatmen and fishermen, but such information should not supersede but guide further investigation. On the result of the above observations will depend the decision as to the place, time, and method of discharge.

An interesting and instructive description of such an investiga-
tion is given in the *Proceedings of the Institution of Civil
Engineers*, Vol. CLVI, p. 355, in a paper by Mr. William Henry
Haigh.

CONTINUOUS DISCHARGE SEWERS

The most favourable state of affairs is when a point can be
found so situated that the current sets outward at all stages of
the tide. A projecting point on an open coast line, for example,
might have the flood tide running up and the ebb running down,
but both tending out from the shore, and in such a case it might
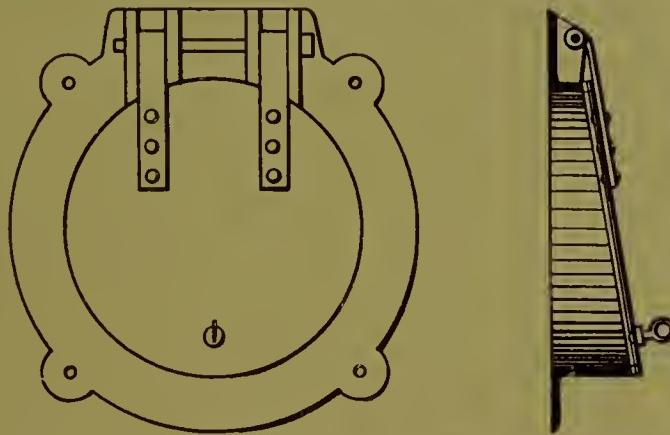
Fig. 55.— Flap Valve.

be quite possible to discharge sewage continuously without
any great risk of it being thrown back. Even then the discharge
would be conditioned by the state of the tide, for the discharge
would not be a uniform one, but would depend on the relative
height of the sewage inside and of the tidal water outside. If
the end of the sewer is unprotected, then the sea-water may
sometimes flow in : it will in fact always do so when the tidal
rise exceeds the accumulation in the sewer. If the outlet is
protected by a flap valve, then the rising tide will close the flap
unless and until the sewage inside rises high enough to overcome
it : but no tidal water will be admitted to the sewer so long
as the valve shuts tightly—which is not always the case. In
these circumstances the sewage rises higher and higher in the
sewer : in dry weather it may rise more slowly than the tide and

the outflow of sewage will be altogether stopped ; while in wet weather the inside rise will be quicker than the outside rise, and the flow will continue without intermission.

Valves.—Flap valves are frequently put on the outer end of the discharge sewer, for the purpose of preventing the entrance of sea-water to the sewers (see Fig. 55). The object is a good one, as the mixture of sewage and of sea-water is a suitable medium for the growth of a class of bacteria which produce very offensive gases, and cause complaints of smell. It is, however, doubtful whether the ordinary flap valve is effective in preventing this : and where the available head is small the weight of the valve is a considerable addition to the work to be done, and causes the sewage to head up in the sewers to a greater extent than would otherwise be the case before it escapes into the sea. If a valve is used it will probably be best to fit it not at the seaward end but at the land-end of the sea pipe, say at the last manhole on dry land. If anything goes wrong it can readily be reached for repair, while a valve at the seaward end needs the services of a diver. In the position recommended a penstock (Fig. 56) is preferable to a flap valve.

Fig. 56.—Penstock.

THE FLOW IN OUTFALL SEWERS

The flow in such sewers, down to the point at which they are filled (and which varies with the stage of the tide and the amount of sewage flow), does not differ from that in ordinary sewers. The special points to be discussed here are those concerning the flow in that part of the sewer which is filled with sewage or a mixture of sewage with sea-water.

As sea-water is heavier than sewage, it is necessary to add about $\frac{1}{40}$ to the height of the column of sea-water in comparing
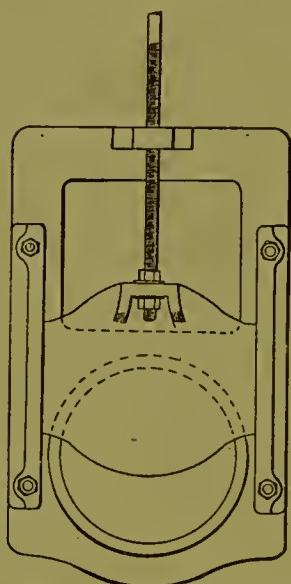
it with a column of sewage ; 40 feet of sea-water would balance about 41 feet of sewage.

The actual gradient of the sewer has nothing to do with the flow under these conditions, and from that point of view it is immaterial whether the gradient be steep or flat.   But as the flow at and near the time of low water—that is, when the sewer is running free—may be a valuable agent in clearing the sewer
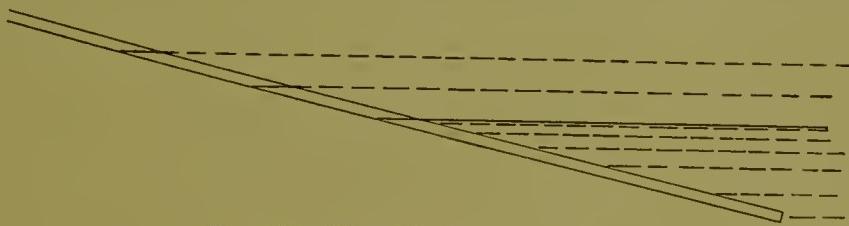

FIG. 57.—Pipe Discharging into Sea.

of silt deposited during the period of stagnation, such a sewer should be designed to have good self-cleansing gradients.   The danger is that these gradients may be mistaken for the working gradient at all times.   The sewer shown in Fig. 57 has its actual gradient equal to its apparent gradient only when the tide is at the low end of the pipe ; it becomes less and less as the tide rises.

The working gradient is merely the head divided by the length.
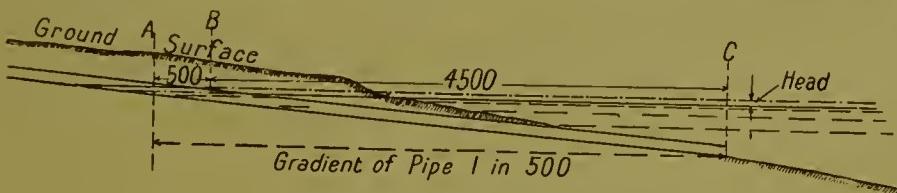
FIG. 58.—Sea Discharge Gradients.

Suppose the sewer in Fig. 58 to be laid at a gradient of 1 in 500.   If the water surface in the sewer at A is a foot higher than the water surface of the sea (plus an allowance—in this case about 3 inches, or $\frac{1}{40}$ of the vertical height of 10 feet—for the difference in weight), and if the length of sewer from the inside liquid surface to the outfall at C is 5000 feet, then the working or virtual gradient is 1 in 5000.   The sewage under the head of one foot has to travel from A to C— 5000 feet—before it leaves the

pipe. If the difference in height is doubled without alteration of length, then the gradient becomes 1 in 2500. Now this gradient is not fixed by the engineer in designing the work, it fixes itself from time to time. At any moment there is a certain flow of liquid in the sewer : the sewer being full whatever the flow may be, the sectional area of the liquid is invariable, and any variation in the quantity discharged can only be effected by a variation in the velocity. To produce a certain velocity requires a certain head. If the head existing is too little, the required quantity of water does not pass, but it rises higher in the sewer, thereby increasing the head until it is sufficient to produce the required flow. If on the other hand the head is too much, the water passes through more rapidly than it arrives, until only the required head is left. There is thus a rise and fall of the water surface in the sewer, which keeps the head automatically adjusted to what is required.

This adjustment of course has its limits. Suppose the volume of sewage at a given moment to be such that a head of three feet is necessary, and suppose that at the same time the tide height is only two feet below the level at which flooding of houses begins. There is thus a foot of sewage available to flood the houses, and the sewer cannot remove it. If the sewer had been properly designed to meet this combination of circumstances, it would have been of such a size that a head of *two* feet would have carried off the required quantity. It does not matter although the sewer running free had a capacity for ten times the quantity : it is not running free.

In practice a storm overflow would be provided, by which the sewage would be delivered to the sea at the nearest point ; but unless the sewer is properly proportioned this will come into action much too frequently—to the detriment of the place from which sewage ought to have been removed. If that happens the sewer is so far a failure.

The discharging capacity of such a sewer must be calculated in exactly the same way as that of a water pipe running under pressure. The moving power is the difference of level between the liquid in the sewer and the open sea outside, the resistance is—practically speaking—the friction in the sewer. Now this

friction depends on the length and on the diameter of the sewer, and on the nature of its internal surface, and the calculation may be made by any reliable formula, such as Kutter's. The velocity and discharge may be taken from the table on p. 37, if the gradient is within the limits of the table, which however is not likely, as these virtual gradients are usually very flat. The gradient *for this purpose* is the difference of level as above, divided by the length. The information required is : The maximum height at which the overflow sill may be set to avoid damage by flooding ; the maximum height of the tide at which no overflow should take place ; the length of the outfall sewer ; and the maximum amount of liquid to be removed per second. The first three give the virtual gradient ; the size of channel required to remove the given quantity of water is then easily ascertained.

Suppose the pipe shown in Fig. 57 to be 24 inches in diameter, its gradient being 1 in 500 as already assumed. Running quite free it could discharge 10 or 11 cube feet per second. But tide-locked as shown, so as to be filled with water for a length of 5000 feet, and with a difference of level of only one foot (in addition to the allowance for the difference in weight), its discharging capacity would only be 3 or $3\frac{1}{2}$ cube feet per second. So long as the level in the pipe was one foot above the level of the sea (with the addition just mentioned), that amount would be passed through. But suppose that the flow increased to 5 feet per second. That would require a head of two or two and a half feet instead of only one, on the assumption that no greater length of the pipe was filled. (Obviously, however, the water accumulating to give that greater head would go further back the pipe, and hence the advantage of the increased head would be partly counter-balanced by the increased length of waterlogged pipe.) Supposing that the highest tide rose to within two feet of the level at which flooding would do damage, the available discharging capacity of such a pipe, with a waterlogged length of about 5000 feet, would only be about $4\frac{1}{2}$ cube feet per second, instead of the apparent capacity of 10 or 11 feet. If under these conditions it was necessary to discharge 11 feet, then a pipe of about 33 inches in diameter would be needed. The design of a sea

outfall must keep in view the two conditions of submerged flow and of open flow, and the sewer must be effective under both these conditions.

The figures just given are purposely stated as rough approximations, as there are various disturbing factors. The coefficient of roughness may be higher than in a free-flowing sewer ; and the head required to produce the velocity, which in ordinary sewers is usually negligible, may in the special circumstances be appreciable.

In the actual working of such a sewer, what happens is this : As the tide rises the virtual gradient replaces the actual gradient higher and higher in the sewer, and the water level in the sewer rises towards the height at which overflow takes place—either harmlessly through a designed overflow, or to the detriment of property. In many sea coast towns it is certain that when there is a high tide in conjunction with a heavy rainfall, the outfall sewer will not carry away all the rain, and a certain amount of overflow must be tolerated. It may happen indeed that there are extreme tides which flood the buildings without any assistance from sewage. A reasonable design for an outfall sewer accepts the fact that if at the top of a high tide the sewers are running full of rain-water, it is not to be expected that all this will be carried away to the outfall. A considerable proportion must be allowed to overflow at the most convenient place, just as in the case of inland sewers it is permissible to discharge storm water over a certain degree of dilution into the natural water-courses. But if a sewer is badly designed, it may readily happen that the virtual gradient required is such that even in dry weather for a considerable time on each side of high water the sewer cannot deal with all the sewage. The result then is that while the sewer is efficient in dry weather and during the lower stages of the tide, the overflow comes into action much too readily. This of course is entirely unsatisfactory, and the construction of a sewer without very careful and intelligent consideration of its numerous requirements is a fairly certain way of putting money into the sea, but a much less certain means of taking the sewage to that destination.

The construction of the overflow is an important matter.

It must have a sill of considerable length, as while the effective level for sewage removal is that of the sill, the effective level for producing floods is that of the water above the sill. Its length, therefore, should be such that a very thin flow over the sill will give a considerable volume of discharge. The sill should be as long as circumstances will permit—a 10-foot sill would not be out of place in connection with a three-foot sewer, and it might quite well be longer. The maximum depth of water on the sill is simply lost head, and every effort should be made to keep it down.

TANK SEWERS

When it is found from tidal observations that a continuous discharge is inadmissible, but that a discharge at certain stages
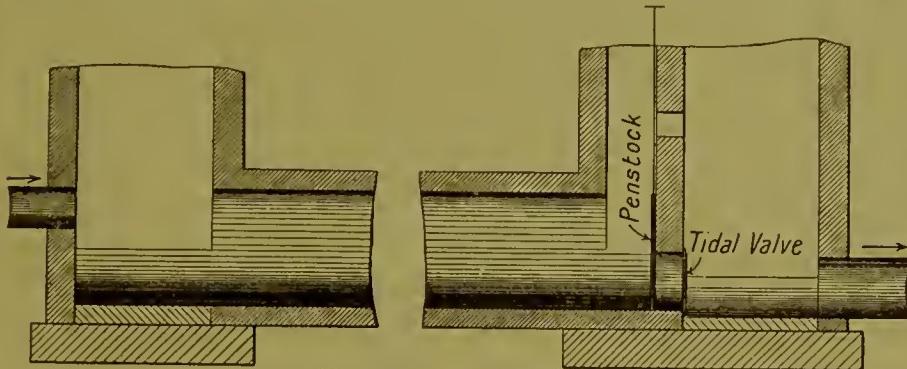
FIG. 59.—Tank Sewer.

of the tide would be unobjectionable, it becomes imperative to store the sewage during the intervals between the times of discharge. This may be done in ordinary tanks, but it is usually found more convenient to do so by what are called "tank sewers." The route of the sewer remains the same, but instead of its capacity being adjusted merely to the flow of sewage, it is adjusted to the amount of sewage which requires to be stored. That amount requires to be calculated from data of various kinds. Fig. 59 shows a common method of constructing such a sewer: the sewer which is normally (say) 18 inches in diameter is made 3 feet in diameter for a considerable distance, and at the low end of the enlargement a control arrangement is provided. It will be noticed that the use of a tank sewer implies a loss of head

equal to the difference between the inlet and the outlet level. In the case such as that shown the loss is the difference of diameter of the two circles, or 18 inches.

Time of Storage.   From high water to high water is a little over twelve hours, and it may therefore be said approximately that the tidal day is divided into four periods, each a little over six hours, with the tide alternately flowing and ebbing. Anything discharged on the ebbing tide will in the first instance be carried seaward, while anything discharged on the flowing tide will be carried landward. But anything discharged on " the turn of the tide " whether at high or low water, will have little or no tidal current to act on it, and may be drifted shoreward by wind or otherwise : while anything d:scharged when the ebb is nearly complete may be carried a short distance seaward and then brought back by the flood. Of course the circumstances of each individual place differ from any others, but it is usually inadvisable to have any discharge until the ebb has become quite pronounced, and the discharge ought to stop before the ebb is nearly complete. The outflow of sewage, therefore, should not begin until about an hour after high water, and should cease about an hour before low water, thus leaving a gap of about eight hours in each twelve and a half during which there is no discharge. Further, the rate of discharge during the remaining four hours must be such that the sewage collected during the interval, as well as the sewage coming down during the discharging period, will be cleared out during that period. It is evident, therefore, that the size of the tank sewer, which provides the storage accommodation, and of the delivery sewer which provides the discharge, are governed by rules which have no counterpart in the design of ordinary sewers.

The Capacity of Tank Sewers.—Assuming then the period during which no sewage can be discharged, usually called the period of " tide-lock," to be about eight hours of each tide, it follows that the tank sewer should be of such capacity that it will hold all the sewage which may reach it during that time, without allowing it to rise to a dangerous level. But it is to be

assumed that the sewers leading to the tank sewer are relieved by means of storm overflows, exactly as sewers leading to purification works would be ; and still further, that a degree of dilution less than that which would suffice in the case of an inland stream might be quite sufficient in many cases for discharge into the sea. It would probably be quite fair in most cases to say that if the tank sewer could retain three times the dry weather flow (of standard sewage) for eight hours, it would be sufficient. This is a point, however, on which no general rule can be laid down, as the local conditions, and especially the nature of the place available for overflow discharge, exert a great influence.

The Discharge of Tank Sewers.—The sewage having been stored, it is necessary to make provision for its discharge at the proper time. The tank sewer is not carried full size to the outlet, but it is connected with the actual point of discharge by means of an outfall sewer. This outfall sewer has to discharge under a varying head, depending on the level of the tide outside and the level of the sewage inside, and it must be so proportioned that it is able under these conditions to deliver in four hours the sewage flow of twelve hours. In other words, the discharging capacity of the outfall should be three times that of the sewers entering the tank sewer, because the one has to take out in four hours what the other brings in twelve. It may be quite properly suggested that the full delivery into the tank sewer is not likely to continue for a period of twelve hours : but on the other hand it is to be remembered that three times the dry weather flow does not represent a specially heavy rainfall if the area is at all extensive compared to the population. Again, however, this is a proportion which must be adjusted after careful consideration of the actual circumstances, no general rule can be laid down.

Tank Sewers and Smells.—Any sewer which is alternately full and empty, or which has its walls alternately wet and dry, is apt to be offensive. Where possible, it is desirable that tank sewers should be constructed out of the way of traffic, and that any ventilators should be in places where escaping gases would not be a nuisance.

Management of Tank Sewers.—The very essence of the working of such sewers implies that the times of opening and closing should be under careful and reliable control. If the system is purely gravitation, the tank sewer is at such a level that it discharges only during the low part of the tide, and it is therefore essential that the outlet valve should be closed at the proper time, otherwise the tide will fill up the space intended for sewage and render the tank quite inoperative. The use of tank sewers is open to less objection in the case of large towns where a skilled staff is available than in the case of small towns : in the latter the management is apt to be given to any handy man, and the result seldom justifies the somewhat heavy cost inseparable from the construction of such a sewer. When the outflow is not merely by gravitation, but when all or part of the sewage has to be pumped, it follows that skilled labour has to be provided to look after the machinery, and if this is near the valves controlling the tank sewer the work of supervision is simplified. In such circumstances a mechanical record of the various operations is easily kept, and any slackness is thus recorded.

The manipulation of tidal valves is of course not an operation which can be done as a matter of routine at a fixed time each day. In addition to the variation caused by the varying time of tide there is a further and uncertain variation due to the amount of sewage and of rain-water : and there is of course the discomfort of having to be in attendance at hours ranging all over night and day, and in all conditions of weather. The management of tank sewers is therefore not a thing to be lightly undertaken, and it is scarcely wise for a small place to consider this as a satisfactory method of sewage disposal.

CONSTRUCTION OF SEA OUTFALL SEWERS

The material used is as a rule either cast iron or steel, and the method of construction depends on the nature of the shore. Of the numerous methods, the following may be mentioned.

Cast Iron on Concrete Blocks.—The construction shown in Fig. 60 is convenient when the sewer runs over an open beach at or

near surface level. Concrete blocks are provided at each pipe length, and the pipe is secured to them by iron straps. There is no great difficulty at the inshore end, but the work becomes more and more difficult as it approaches low watermark. It is tidal throughout, but the period available for working becomes less and less as low watermark is approached.

The work becomes very tedious, as even the short period which would normally be available is liable to be rendered useless by
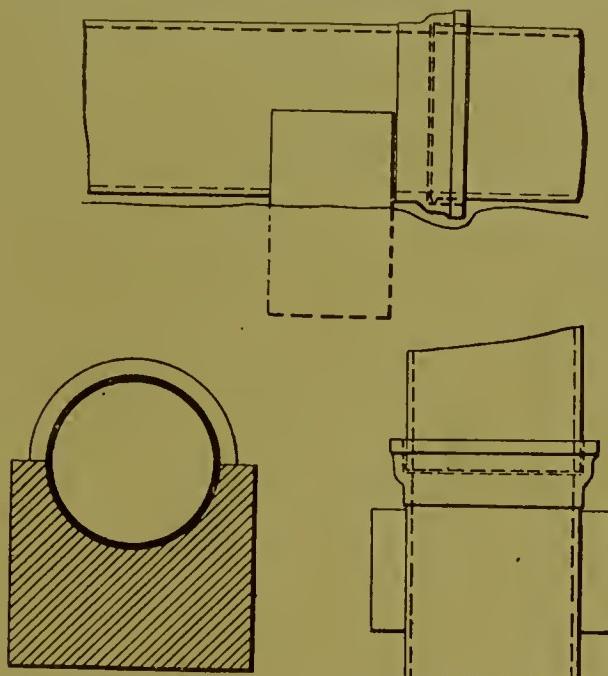
FIG. 60.—Cast Iron Pipe on Concrete Blocks.

rough weather; and except in summer it may be largely lost through coinciding with the hours of darkness. When the work has to be done below low watermark it becomes altogether a matter for divers. A 12-foot length of cast iron pipe of any considerable diameter is of substantial weight, and calls for powerful tackle if it is to be handled expeditiously.

Steel Tubes.—These have the advantage of much less weight, and can either be had in considerable lengths with ordinary joints, or can be built up to any required length by riveting. If it is necessary to carry the outlet to any considerable distance

beyond low watermark, and if the beach is suitable, a very convenient method of working is to build the outfall sewer on the beach, just below the high watermark of spring tides. When it is completed and ready to be put in place, the ends are plugged and the whole pipe becomes a pontoon. It can then be floated out to its intended position, its bed having been previously prepared, and by the gradual admission of water its
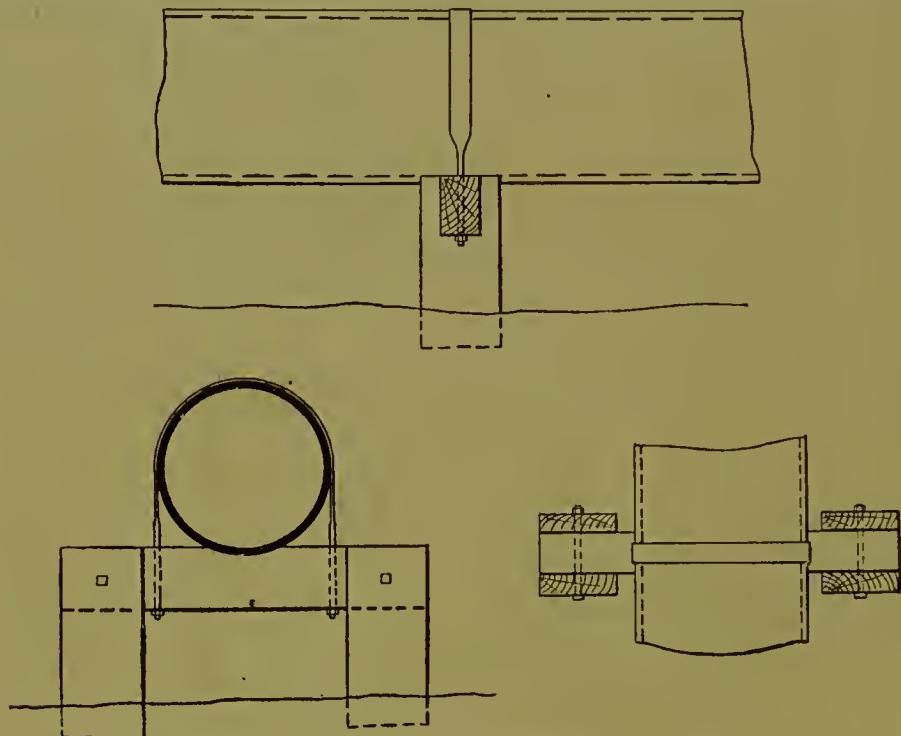
FIG. 61.—Cast Iron or Steel Pipe on Piles.

buoyancy is destroyed and it sinks into place. The operation of launching, floating out, and sinking is a somewhat anxious one, but otherwise there is no special difficulty. The steel tube is not nearly so dependent on having a smooth and uniform bed as an iron pipe would be : it has considerable flexibility, and an accident which would smash an iron pipe would merely dint a steel one. Steel tubes may be used on the foreshore as well as below low watermark, although it is for the latter position that their special qualities are most useful. Fig. 61 shows a method of supporting such pipes at any required height above a sandy bottom.

CHAPTER X

THE need for ventilation in sewers is one of the points on which opinions differ to a considerable extent. In the majority of places provision is made for ventilation, in some it is neglected, while in others—Bristol being the best-known example—such provision is deliberately omitted.

Reasons for Sewer Ventilation.—If anything occurs to compress the air in the sewers, and if there is no provision (intentional or otherwise) for its escape, this air will be forced from the sewers into the house drains, in spite of the resistance offered by the intercepting traps. As an ordinary trap on a house drain has only a resisting power equal to about one or two ounces per square inch (see *Modern Sanitary Engineering*, Part I, Chapter VIII) a very slight increase of pressure in the sewer will overcome this resistance. The increase of pressure might result from the rise of the tide or from the rapid increase of the volume of sewage itself, due for example to a heavy shower.

It is argued further, that if sewers are unventilated the contained air or gases may become so foul as to involve serious risk to those who have to enter the sewers. This of course only applies to sewers of such size that men can work in them.

" Importance of Sewer Ventilation Exaggerated."—The question of sewer ventilation is discussed in the Report of the Departmental Committee of the Local Government Board appointed to inquire into the use of Intercepting Traps. The Committee was appointed in 1908 and reported in 1912, having in the interval taken evidence and conducted experiments. The heading of this paragraph is one of the headings of its Report, which is

generally to the effect that sewer ventilation, even when elaborate appliances are provided for it, is largely imaginary : and that it is of comparatively little consequence.

It was not found that pressure accumulated in a sewer, even to the small extent necessary to force the seal of an intercepting trap, unless the connection of the branch drain with the sewer was actually submerged. In other words, the sewer was always so far from being airtight that the air imprisoned by the rising water escaped through the sewer walls at a sufficient rate to prevent such a pressure being reached, so long as the walls of the main sewer were available for this escape. It was only when the water had risen so high as to cut off all aerial connection
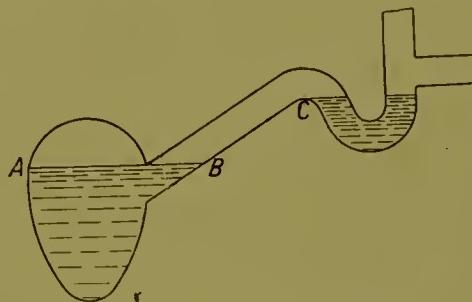
FIG. 62.—Airlocked Branch.

between the sewer and the branch drain, that the further rise of water in the latter produced the required pressure. The reason obviously is that while the sewer has a large internal surface, and in the case of brick sewers has numerous joints : the connecting drain is a pipe of small diameter and may be very short. Fig. 62 shows this condition. The main sewer is shown in cross-section, and when the flow in it has reached the level of the line A B, the air between B and C is isolated from the main body of air in the sewer. Any further rise produces in the branch a pressure which cannot be relieved by leakage through the sewer itself. Unless, therefore, there is leakage between B and C— that is, through a small and short pipe—the pressure comes at once on the water of the trap.

With regard to danger, it was found that accidents were not rendered impossible even by free ventilation of the sewers; and that the same precaution was necessary in ventilated as in

unventilated sewers, namely, free local ventilation by opening manhole covers some time before men entered the sewer.

Intercepting Traps.—The Report just quoted has greatly changed the position with regard to these traps. It had long been assumed that " sewer gas " was so much more dangerous than the air of drains that every effort must be made to keep sewer gas from entering the drains. The Report states definitely that, " The bacterial danger of sewer air is incomparably less than the bacterial danger of drain air ; and that, therefore, the entry of sewer air, into a house, is of correspondingly smaller importance, bacterially, than the entrance of drain air." This being so, the chief reason for the intercepting trap disappears ; and though it will still be used to a large extent from the feeling that it is an additional safeguard, there is little doubt that it will gradually be discontinued. The author has long held that the proper course is to make the drainage system of the house so good that no air from it can enter the house : and he is therefore in complete accord with the findings of the Committee.

Sewer Ventilation through House Drains.—If the intercepting trap were abolished, the problem of sewer ventilation would disappear. Each house which contributed to the sewage flow would contribute to the ventilation, in something like the same proportion. Instead of having special appliances for ventilation, the pipes which are already required for the drainage of houses (and for the ventilation of these drains) would serve to ventilate also the sewers. The aggregate amount of ventilation would be much greater than is possible under any system of special ventilation, and the distribution would be much better.

Until lately this was impracticable. The belief that sewer air was extremely dangerous had found expression in by-laws endorsed by the Local Government Board, and almost universally accepted—that every house drain must have an intercepting trap just above its connection with the sewer. The Board refused to sanction by-laws which did not contain this provision. In view of the Committee's report it may be assumed that the requirements will at least be modified. Ultimately it

may be expected that the problem of sewer ventilation will be satisfactorily solved in this simple manner.

This method of sewer ventilation has many advantages: The openings are all above the roofs, and are necessary in any case for another and similar purpose—namely, drain ventilation. The latter is needed for reasons quite other than those which apply in the case of sewer ventilation. The openings are of ample size, and are distributed as fully as are the ordinary inlets: there can therefore be no dead ends. There is not only no extra cost, but the cost of the intercepting trap and its accompaniments is saved. There is no chance of the ventilators being seriously obstructed: a drain airpipe here and there may be obstructed, and this may be serious for the individual house in which it happens; but it is inconceivable in any well-ordered town that this should be so prevalent as to have any appreciable effect on the general sewerage system.

The new main drainage system of Cairo, as described by Mr. Carkeet James (*Proc. Inst. C.E.*, Volume CCII), is ventilated through the house drains. A new village of 250 houses has recently been built at Glengarnock, Ayrshire; and on the advice of the author and with the approval of the Scottish Board of Health, intercepting traps were omitted. It may probably be assumed that sanction will not now be withheld, either in England or in Scotland, from any properly designed scheme on similar lines. (See Chapter XVIII.)

Limitations of this Method.—The only objection is that which has already been indicated—that the admission of " sewer gas " to the house drain has long been regarded as dangerous. In spite of the high authority of the Local Government Board Report, it may be expected that this belief will die slowly, and that by-laws embodying the old requirements will long be in force. Even where the requirements are changed, there is the probability that the change will merely be permissive, and that the use of intercepting traps will continue to some extent even when they are no longer compulsory. They are practically universal in existing systems of house drainage, and it will be a long time before there can be any very marked change. While

therefore there need be no hesitation in depending on house drains for sewer ventilation in new districts, it will be necessary for many years either (1) to abandon the requirement of ventilation or (2) to make special provision for it.

No Ventilation.—This system has in few cases been deliberately adopted, and has been regarded by most sanitarians as indefensible. But in view of the Report above mentioned, it is evident that those who adopt it cannot be altogether condemned. On the other hand, it is to be remembered that the freedom from evil effects in unventilated sewers is attributed (in part at least) to the imperfections in construction which make sewers far from airtight, and that in so far as airtightness is approached, in a corresponding degree sewer ventilation becomes desirable. In other words, the ventilation which is not provided by authorised openings is provided by chinks and flaws in the construction of the sewer, and hence the better the construction the more need there is of ventilation. It will be observed too that this is not " ventilation " in the ordinary sense, which implies the free passage of an air current ; but only what is sometimes called " venting " or providing means for the prevention of pressure.

On the whole, it might be said that where the Local Authority is not prepared to introduce ventilators, it would probably be better to abolish the intercepting trap and so ventilate the sewers through the house drains, than to depend for ventilation on the imperfections of the sewers. This implies, however, that proper attention is given to the condition of the house drains.

It will often be necessary to provide for ventilation to some extent, even if it were only to satisfy public opinion. The following methods are therefore mentioned.

Ventilating Gratings on Street Surfaces.—This is probably the most common method, although it is condemned in the Report above quoted. It is usually combined with manholes, the grating which gives access to the manhole being left open in whole or in part for ventilation. A " mud box " is provided below the grating, in order to intercept solid matters which may fall through (Fig. 63).

The system has the advantage of simplicity. Manholes and covers are needed in any case, and the additional cost of making them act as ventilators is trifling.

On the other hand, any offensive gases which escape from such openings do so under the noses of passers by, and the ventilators may thus be very objectionable. The weight of this objection is dependent to some extent on the condition of the sewers :

Fig. 63.—Sewer Ventilator with Mud Box.

with sewers in good condition it is surprising how little smell is usually noticeable, but where the sewers are foul, or where they receive offensive trade discharges, the ventilators may become a serious nuisance. Except in the case of offensive trade discharges the risk is associated chiefly with outlying or suburban sewers. The main sewers are fairly well proportioned to their work, but the sewers in suburban or semi-developed districts are provided in prospect of future requirements, and the present flow may be very small (compare p. 23). In periods of dry weather such sewers are very apt to be foul, and the smells escape through the ventilators to the discomfort of the neighbourhood. It is for this reason that there is the apparent anomaly of street surface ventilators comparatively inoffensive in a crowded town and seriously objectionable in the suburbs or in country districts.

Charcoal trays.—It was at one time common to provide under each grating a tray of loose pieces of charcoal, the intention being that the escaping sewer gases would be deodorised by contact with the charcoal. But the charcoal soon became consolidated and practically stopped all passage of gas. The " spiral tray " of Mr. Baldwin Latham was one of the most successful, but altogether the principle was not satisfactory.

The covers required for sewer ventilators of this type are considered more fully in the chapter on manholes.

Chemically Treated Openings.—In order to obviate the objection to the above method of ventilation, chemical methods have sometimes been adopted. The " Reeves " method is perhaps

the best known, and consists in placing in the manhole a recep-
tacle containing manganate of soda, which is dissolved by a
slow flow of water from the main. The solution mixes with a
flow of sulphuric acid from another vessel, thereby producing
permanganate and evolving permanganic vapour, a strong
deodorant. Quite satisfactory results have been obtained, but
the system involves not only a substantial capital outlay in
providing and installing the apparatus, but a constant charge
for water and chemicals.

High Shafts.—In the case of narrow streets flanked by high
buildings, independent shafts are scarcely
practicable, and if high shafts are used at all
they must be fixed to the buildings. This in-
volves interference with private property, and
if it is proposed to put up such ventilators in
the ratio of, say, one to every 50 or 100 yards of
sewer, the owners and occupiers of the property
which is so used may have a grievance. The
ventilation of a considerable length of sewer is
concentrated and brought into their immediate
neighbourhood, while those in adjoining houses
escape.

Fig. 64.
Ventilating Shaft.

If, on the other hand, the district is one of
wide roads and houses of no great height, it
may be possible to erect special ventilating columns, similar to
tramway standards or lighting columns, at the side of the foot-
path (Fig. 64). These columns are usually of cast iron, and
have an internal diameter of not less than four or five inches,
often considerably more. The connection to the sewer is made
by a drain pipe, and provision is made to intercept any
matter which may either scale off from the inside of the shaft
or which may be dropped into the shaft—by birds for example.
This is an important provision, as a shaft with a mere bend at
the foot, followed by a flat drain through which no liquid ever
runs, is very apt to become choked in this way. A box or
pocket to collect any such debris is essential, and of course
should receive regular attention.

Heated Shafts.—In conjunction with such shafts, various methods of using gas have been adopted. Sometimes the ordinary lighting arrangements have been used, the supply of air being from the shaft instead of from the surrounding atmosphere. At other times a special gas furnace has been formed inside the base of the post. The former utilises—during the hours of darkness—the gas for the double purpose of lighting and of cremating the sewer gas : the latter has the advantage that it not only cremates the sewer gas but by heating the shaft it converts it into a chimney with a more or less powerful updraught. While such appliances have been used from time to time with satisfactory results in the cure of local smells, they have not come into general use, partly because of their cost and partly because the motion of air in the sewers is apt to be determined by the wind more than by any artificial control.

Upcast and Downcast Shafts.—The endeavour has sometimes been made to distinguish between the openings into the sewers, classifying some as upcast shafts, by which the more or less polluted air leaves the sewers, and others as downcast shafts, by which the fresh air enters. If this distinction could be ensured in practice, then obviously the former only can become offensive. It can scarcely be said, however, that this has been done : the great ramifications of the sewers, their varying degree of tightness, the varying conditions connected with house connections, and the influences to which the air in the sewers is subjected, make it scarcely possible to have such effective control.

Air Currents in Sewers.—Numerous experiments have been made, those by the late Mr. T. de Courcy Meade being probably the most exhaustive. The conclusions which he reached are very instructive, and the author was indebted to him for permission to repeat them :—

(*a*) Where shaft ventilation only is relied upon, some of the shafts become inlets and others outlets.

(*b*) These conditions are not continuous, the directions of the air currents are at times reversed, the outlets acting as inlets, and *vice versa*.

(*c*) The air currents within the sewers are governed to a large extent by the differences between the external and internal temperature, the flow of sewage, the construction and character of the sewer and other local circumstances.

(*d*) All these conditions are neutralised, and at times reversed by the change of direction and force of the wind.

(*e*) Ventilation by metal shafts is affected, and in some cases materially assisted, by the heat of the sun.

(*f*) No general rule can be laid down which would be applicable to all cases and under all conditions.

(*g*) Under normal conditions, in properly constructed and regularly flushed sewers not receiving trade refuse, the perceptible odours are less when they are unventilated than when ventilated.

(*h*) Air currents do not invariably flow from lower to higher levels, the reverse being frequently the case even when gradients are steep.

(*i*) Air in sewers in partial use is generally more offensive than that in similar sewers which are used to their full or nearly full capacity, other conditions being equal.

(*j*) That the regular and efficient flushing of sewers with fresh water is a more important desideratum than the introduction of large volumes of air. A case in support of this view may be quoted where intermediate manholes were inserted in an old sewer in fair condition, which increased the ventilation openings by 100 per cent, but did not appreciably improve the condition of the air within the sewer. Flushing was resorted to and a marked improvement was immediately effected.

(*k*) All methods which replace or retard natural ventilation are inadvisable except under very exceptional circumstances.

(*l*) Ventilation of sewers is necessary for the safety of the workmen, and for the free escape of air when sewers are rapidly filled in times of storm.

(*m*) Methods usually adopted in the ventilation of mines cannot be successfully applied to sewers.

It will be observed that while a number of these conclusions are in support of current practice, they point to a number of factors to which little attention has been paid. The conclusion

lettered (*l*) is only partially in accordance with that of the Departmental Committee previously quoted : it may be that either of them admits of many exceptions due to local conditions.

General.—In probably the great majority of cases the problem of sewer ventilation will remain one to be tackled in a more or less haphazard manner, surface ventilators being used in most cases, and other methods being tried when special complaints are made ; unless and until the abandonment of the intercepting trap ensures that each house which contributes to the sewage flow will also contribute to the sewer ventilation. This undoubtedly is the logical conclusion : how far it is from practical realisation it is impossible to say.

CHAPTER XI

It is necessary to provide means of access to sewers for the following purposes : Inspection : removal of accidental obstruction or deposit ; and (in the case of built sewers) repairs. The same openings are frequently used for the purpose of ventilation.

Manholes are openings large enough to allow a man to descend to the sewer level, thus giving facilities for the execution of any work and for direct visual inspection of the sewer. Lampholes are a cheaper contrivance, which afford certain facilities for inspection, but which are too small to admit a man. They are now very little used. Their function is to provide light (by a lamp lowered from the surface) at one end of a section of sewer, so that from a manhole at the other end a man may look through the section and see whether or not it is clear.

Number of Manholes.—It may be said generally that in planning a sewer system a manhole is provided at every place where direction or gradient changes, or where a connection with another sewer occurs. There is thus a straight line without sewer connections from manhole to manhole. Intermediate manholes are added if the length of these straight lines is excessive, and the permissible length between manholes varies greatly. The tendency to restrict the number is least when the sewers themselves are of costly construction, as the extra cost of manholes is not great in proportion : in the case of pipe sewers on the other hand manholes are a serious proportion of the cost, and their number is restricted as much as possible. Roughly it may be said that while in large built sewers manholes are often provided at distances not exceeding a hundred feet apart, it is more common in small sewers to find them about a hundred *yards* apart. The number must be determined by comparing

the primary cost of a manhole, on the one hand, with the cost
and inconvenience of having to open the sewer in default of it.
In some cases it might be very easy to reach the sewer by digging
—say in the case of a shallow
sewer passing through open
ground of no great value : in
another it might be a most
serious operation—say in the
case of a deep sewer in a con-
gested street. In the former
case the minimum allowance of
manholes would be made, in
the other the maximum. In theory it should be possible to
reach any part of the sewer from the manholes—by the actual
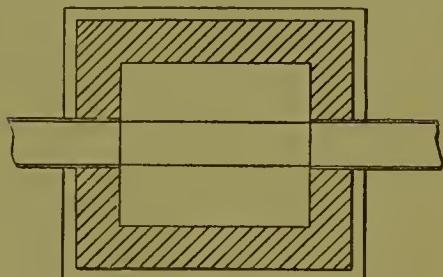
FIG. 65.—Manhole, Plan.
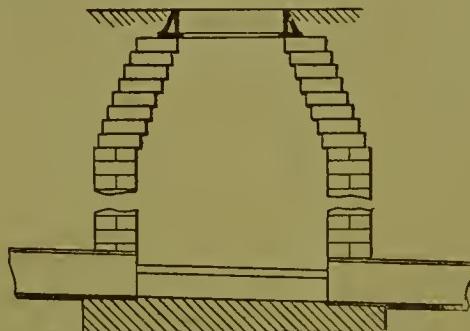
FIG. 66.—Manhole, Longitudinal
Section.
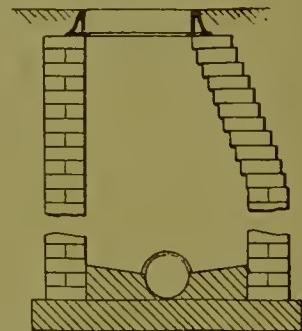
FIG. 67.—Manhole, Cross
Section.

entrance of the sewer men to large sewers, and by rods in small
sewers. But it is seldom necessary to put rods through a well-
designed and well-constructed sewer, and it is often legitimate to
take the risk of having to make a special opening if needed.

Construction of Manholes.—The usual form is a brick shaft
founded on concrete, Figs. 65, 66, and 67. The concrete founda-
tion forms the channel through the manhole, and is shaped to
meet the incoming and outgoing sewer, as well as any branches.
In some cases the manhole has the lower part of the sewer as
its foundation, the shaft to the surface merely replacing the
semicircular roof of the sewer, Figs. 68, 69. This design gives a

uniform section through the manhole, but there is no benching on which a man may stand when he has occasion to enter the manhole. In any case the foundation must be enough to carry the structure, and the shaft must be strong enough to resist the earth pressure on the outside.

The shaft is usually rectangular or circular. The latter is strongest for a given size and thickness, but the former is cheaper bulk for bulk, so that as regards cost there is little to choose between the two. Individual preference has most to do with the
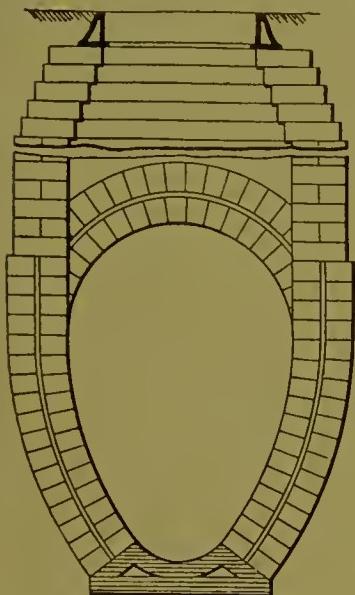
FIG. 68.—Manhole, on Sewer Invert Blocks. Cross Section.
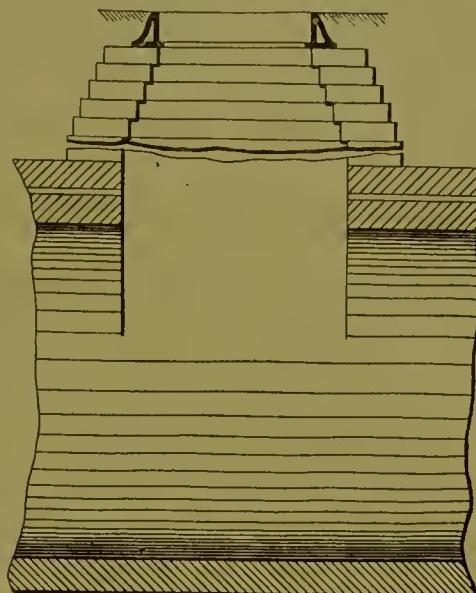
FIG. 69.—Manhole on Sewer Invert Blocks. Longitudinal Section.

choice in any given case. There are considerable limits between which the thickness is the same whatever the shape. Sometimes, but more rarely, the shaft is oval.

Thickness of brickwork.—$4\frac{1}{2}$-inch brickwork is only used for manholes of trifling depth, in ground free from traffic. Practically speaking, 9-inch brickwork is the thinnest that is used. This is usually strong enough in the case of rectangular manholes, for depths up to about 12 feet, beyond that 14-inch brickwork is used for the lower part. If the manhole shaft is circular the 9-inch brickwork may be continued to a greater depth, calculated

in the same way as the thickness of sewers. Bad ground will in either case call for increased thickness.

Size of Shaft.—The minimum size may be taken as 3 ft. 6 in. long and 2 ft. 6 in. broad : or 4 ft. long and 2 ft. broad. The latter size is sometimes adopted when the manhole is built on sewer invert blocks. In the case of a circular manhole a diameter of 3 ft. might serve for the smallest sewers, but 3 ft. 6 in. would be more satisfactory. All of these sizes would be increased if the sewer itself were of large size or if on account of junctions or otherwise special freedom of movement were necessary.

Even the smallest shaft is larger than the surface opening,
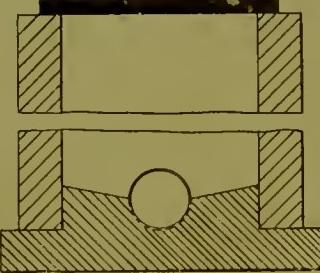
FIG. 70.—Manhole with Stone Cover.
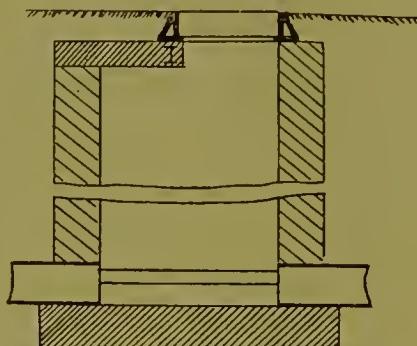
FIG. 71.—Manhole with Concrete Cover.

which is limited (see p. 133) to the smallest size that will conveniently admit an ordinary man. When the manhole is a deep one, there is no difficulty either in turning a brick arch over part of the manhole or in drawing in or " corbelling " the brickwork so as to make the shaft taper from the larger to the smaller size (see Figs. 66 to 69) : but in shallow manholes there is not room to do this. The arch would come too near the surface, and the required corbelling would be too fast for safety. In such cases the manhole may be partly covered with slabs of stone (Fig. 70) or of concrete (Fig. 71) supported by steel bars under the stone or in the concrete, if the span is greater than would be safe without such assistance.

The manhole should not be diminished in size within three feet of the sewer invert (more if the sewer is large) : otherwise the

space is too little for a man to work. Another three feet is re-
quired for convenient tapering, and about a foot for the cover,
so that if the total depth to invert is much less than seven feet
it is advisable to resort to some means such as those just men-
tioned of partially covering the top, beside the usual cover.
If on the other hand the manhole is very deep, say beyond 10
feet, it is necessary to see that the tapering is not made so fine
that the shaft is too narrow near the top. It is one thing for a
man to go down through a small manhole cover into a fairly
roomy shaft, but it is a different thing if the shaft continues for
a considerable distance little bigger than the opening through
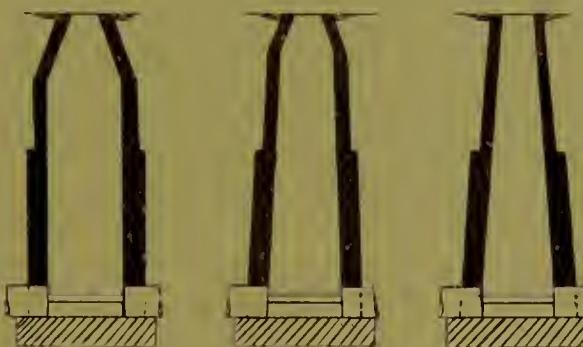
Fig. 72.—Diagram Showing Taper of Deep Shafts.

the cover. If, therefore, the shaft is a long one, it is better to
bring it up undiminished to within about four feet of the surface,
or to have the taper of the upper part more pronounced than the
taper further down, so as to ensure that a reasonable space will
be available in the shaft, than to have a uniform taper throughout
(see Fig. 72).

Steps should be provided in the walls. These are either of cast or
wrought iron : the former has the advantage of greater thickness
and consequent longer resistance to corrosion, while the latter
are stronger. In a rectangular manhole the steps may consist
of straight bars crossing one of the corners, but a more usual
method is to have the steps made of U shape (Fig. 73), the straight
ends being built into the brickwork. It is convenient in the latter
case to have the steps " staggered " as shown in Fig. 74 rather

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than to have them vertically above each other. A suitable spacing is about 15 inches apart, that is, 30 inches apart in each row.

Manhole Covers vary according to the ground surface. In agricultural land it is customary to end manholes (when not
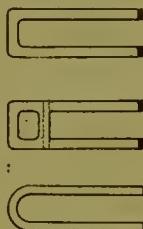
Fig. 73.—Manhole Steps.
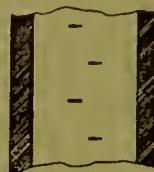
Fig. 74.—Arrangement of Manhole Steps.

required for ventilation) about 18 inches under the surface, and to have a stone cover. The reason is that while it may be convenient to have a possible means of access, it is seldom required, and the buried cover does not hinder agricultural operations. The "wayleave" charge for such a manhole is therefore less than for a manhole which is a permanent obstruction. As against this there is the certainty that if opening does become necessary more surface damage will be done, but the disturbance is trifling if an accurate record of the manhole position is kept.

On street surfaces cast iron covers are used, and of these there are numerous patterns.

Fig. 75.—Manhole Cover, Square.

Figs. 75 and 76 show popular forms. The requirements are that they should be strong enough to carry the traffic, wide enough to give reasonable passage, and that they should not form a dangerous obstruction. To these is sometimes added the further requirement of providing for ventilation without admitting dirt. Hard wood blocks are often inserted in order

to give foothold for horses as shown in Fig. 76. Locking covers
are sometimes used, but the general practice is to use covers
which rest in place merely by their weight : locks which will be
satisfactory under such conditions of use are scarcely to be
found, and keys are not always available
when urgently wanted.

FIG. 76.—Manhole Cover
with Hard Wood Blocks.

Hinged Covers are not so satisfactory
as plain lifting covers. The road material
gets into the hinges and hinders the
opening, and it is often difficult to get
them turned back sufficiently to be safe.
When hinges are used it is well to have
no part of the frame behind the hinge as
in Fig. 77, the part shown by hatched lines being omitted, as it
is easier to clear away the abutting macadam than to pick out
the detritus from a narrow space. When the hinges are quite
clean it is easier for unauthorised people to tamper with them
than in the case of lifting covers.

Causeway Border.—The ordinary cover has a rectangular
edge, and this is apt to project above the road surface by the
wear of the latter if the cover is not surrounded by causeway

FIG. 77.—Manhole Cover,
Hinged.

setts. In macadam roads therefore it is
necessary to provide for a surround of
setts, laid on a concrete foundation
(Fig. 78). If the cover is circular these
must be of small size, 4-inch cubes
being convenient, or the stones must be
dressed to curve, which is expensive.
Even with rectangular openings it will
often be found convenient to use these
small cubes rather than the larger stones. The object is not so
much to have an unyielding and indestructible surface as to
have one which will remain up to its level where it is in contact
with the iron, so as to prevent the formation of any sudden
step. There is, of course, a similar danger at the outer edge of
the stone work, but the stone wears away more readily than

the iron, and the step is not usually so pronounced. At best, however, it is apt to be appreciable, and close attention is required to prevent it becoming an obstruction.
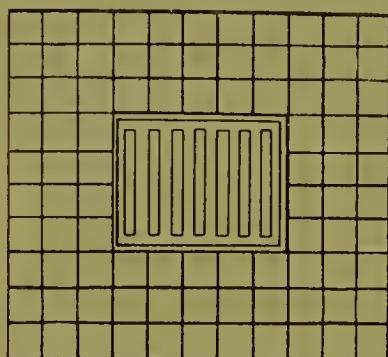
FIG. 78.—Manhole Cover, sur-rounded by Causeway.

Domed Covers. Another means of getting over the difficulty is to make the iron cover of a dome shape, and to omit the stone altogether (Fig. 79). This was introduced by Mr. S. H. Adams, and has in various forms become very popular. At first it was difficult to get covers of this form with sufficient strength to resist the heavy traffic of main roads, but this trouble now seems to have been overcome. In comparing the cost of the two types, it is fair to credit the domed covers with the saving in causeway setts, except when these would be required for other reasons—such as for crossings. In causewayed streets, or other places where the covers are surrounded by hard and unyielding materials, there is no object in using these covers.

Mud Boxes.—It is not desirable that street mud should enter the sewers, as it readily becomes compacted. Where covers are formed with perforations for ventilation, it is usual to have mud boxes under the perforations, in order that any mud which passes through may be caught (see Fig. 63, p. 120). These boxes are

FIG. 79.—Manhole Cover, Domed.

usually formed of sheet iron, and it is part of the duty of the scavenging department to see that they are emptied from time to time.

An alternative method of providing ventilation openings and

of protecting the sewer-from the droppings is to have a cover of double pattern—one half being over the shaft and having no openings, while the other is over a side pit of small depth (see Fig. 80).

Size of Manhole Covers. —The minimum size is fixed by the space neces- sary for the passage of a man of ordinary size, and this may be taken as about 18 inches in diameter. As a rule, rather more space is given. A square opening of 21 inches each way is

FIG. 80.—Manhole Cover, Double.

very common, and 24 in. by 18 in. or even a square of 24 inches is often found. The advantage of the small cover is that it minimises the effect on the street surface, and that its narrower
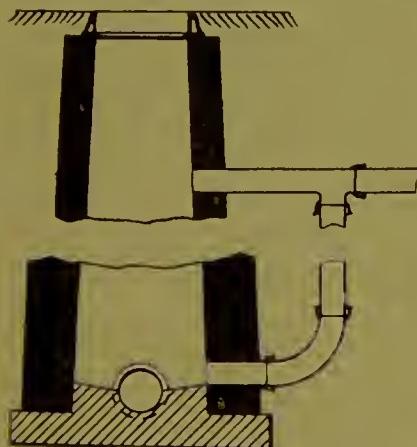
FIG. 81.—Branch Sewer, connection to Manhole.

unsupported span enables it to be made lighter than is necessary with larger covers. On the other hand, the smaller cover requires that the shaft should be tapered to a smaller size, or that the opening should be partly covered by some other means. For a comparatively shallow manhole, which opens out at once by means of a flat roof, the smallest size of those mentioned will not cause inconvenience to the men who have to enter, but for a shaft which gradually tapers for some distance 21 inches square would as a rule be preferable.

Modern traffic developments have made increased strength necessary. The larger sizes mentioned above are usually nine inches and sometimes twelve inches deep, and may weigh about 4 cwt.

Branch connections in Manholes.—Branch sewers are often considerably higher than the main which they join, and it would obviously be awkward to run them into a manhole shaft some distance from the bottom. Unless the flow could be stopped, the manhole would be practically useless. Nor would it always be convenient to bring in the branch with a steep fall to the manhole floor. The arrangement shown in Fig. 81 gets over the difficulty, the branch sewage reaching the manhole floor by the vertical
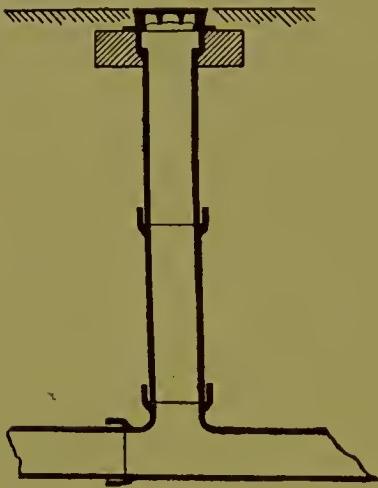
FIG. 82.—Cover, resting on Shaft.
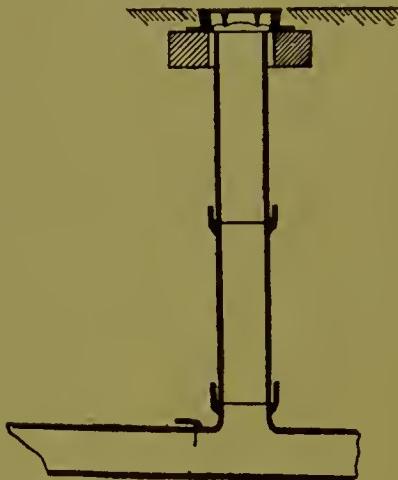
FIG. 83.—Cover, supported independently.

branch and bend, while the continuation of the branch sewer (which may be plugged if necessary) gives a convenient means of inspection.

Lamp Holes.—These may be constructed either as brick shafts or as pipe shafts, the construction being usually the same as that of the sewer itself. It is important in the case of pipes that the surface grating should not bear directly on the shaft (Fig. 82), but should be independently supported (Fig. 83) : otherwise the pressure of traffic is transmitted directly on to the sewer pipe and may readily break it. The diameter needs to be no larger than is required for lowering a lamp ; a 9-inch pipe is quite suitable.

CHAPTER XII

STREET GULLIES

WHEN sewers were first constructed, their purpose was to remove rain-water, and not what is now called sewage. It was a penal offence to discharge the latter into the sewers; and even in comparatively recent times the direct discharge was forbidden, although discharge through an intercepting cesspool was permitted. Now, except where the " separate " system is adopted the one set of channels serves for everything.

It has already been pointed out (Chapter III) that the size of sewers depends chiefly on the amount of rain-water which they have to carry. It is important in designing sewers to arrange for the proper admission of that rain-water. The requirements differ according to the nature of the ground through which the sewers pass.

In a rural district provision for the removal of surface water from roads has usually been made before sewers were thought of, and it often happens that no interference with that provision is necessary. There are alongside the roads gratings and channels for the conveyance of surface water from the road surfaces into the natural water courses, and the new sewers are laid quite independently of these. If they are disturbed by the sewerage operations they are simply restored as they were before. The rain-water which falls on roofs, yards, etc., either reaches the sewer through the house drains, or it too is led off to the natural water courses : in either case special provision for its admission (as distinct from its conveyance) is not needed.

But in town streets special provision is necessary. The facilities for running the water into natural streams no longer exist, and a flow of water of any magnitude alongside the street is not tolerable. It is necessary therefore to make provision

for the removal of water from the surface to the underground channels at fairly short intervals.

The street is formed with a " camber " which causes the water to run off the centre to the sides. The footpath is formed with a kerb, which has a vertical rise (Fig. 84). Hence the water runs to the side of the street adjoining the footpath, and this part, the " water table " in country roads and the " gutter " in streets, is formed in such a way as to give a convenient channel, and with a longitudinal slope. If the street is macadamised, the channel is formed of harder material : while if the whole street surface is of the harder material, the channel may differ to the
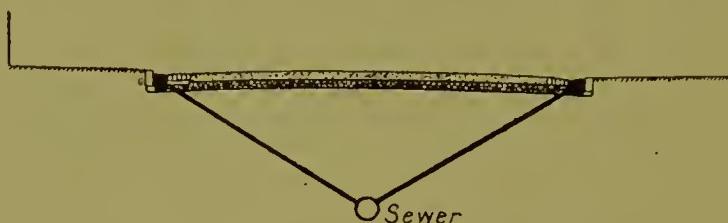
Fig. 84.—Street Section, showing Side Drains.

extent of giving a smoother longitudinal passage. At intervals gullies are provided to take the water from the gutter to the sewer.

Spacing of Gullies.—This is largely determined by convenience of traffic. Where two streets intersect a gully is usually placed in such a position as to catch the water before it reaches the crossing (Fig. 85). If there is a long stretch of unbroken kerb, several gullies may be needed in its length, otherwise the volume of water will in wet weather be inconveniently great before it reaches the gully. Again, if there is little longitudinal fall on the street, it is necessary to space closely to avoid clashing of street and gutter levels. The gutter must have a fall whether the street centre has or not, and a gutter gradient differing from the street gradient cannot be carried far. It thus becomes necessary to make frequent gullies. In very steep streets, again, it is not desirable to have the water running very far in the gutters, otherwise it will acquire a velocity which may cause injurious erosion, and by which too it may leap over the gully

when it does reach it. The gullies at the foot of a steep hill are often overcharged owing to the defective admission of water to those further up.

The spacing varies very greatly, but it may be said generally that 70 or 80 feet is a fair minimum run of gutter into a gully, while as much as 300 feet is not infrequent, the close spacing
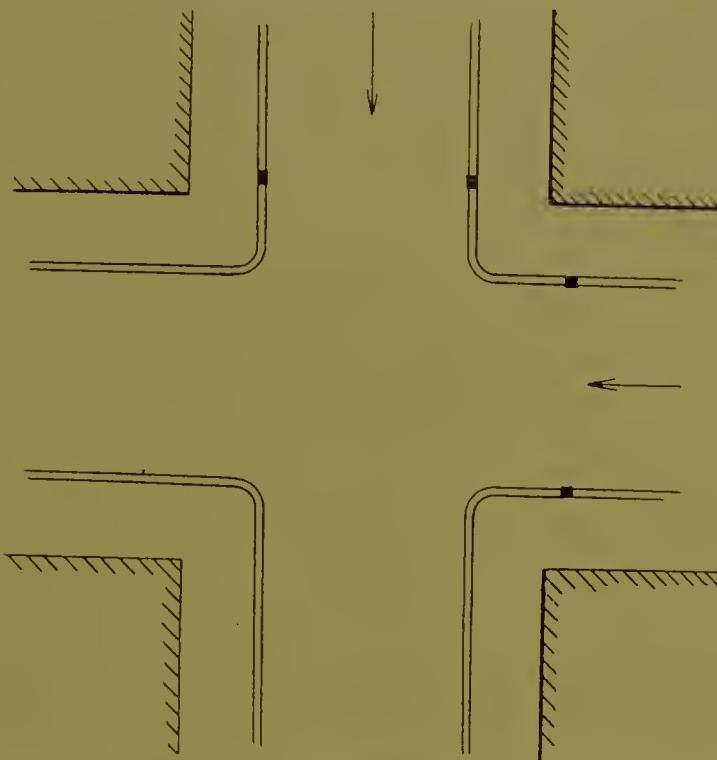
Fig. 85.—Gullies at Street Intersection

being applicable to flat streets. The actual distance apart of the gullies may be double these lengths, when a hollow and a summit occur alternately. Those who are responsible for town streets prefer usually to have a liberal allowance of gullies, and thus to have a very limited surface flow. The gratings may then be smaller than if each had to receive the drainage from a large area.

Gratings.—In country roads large wrought iron gratings are often used, but these are generally kept out of the probable course of wheeled traffic. In towns it is inevitable that wheeled

traffic should pass over the gratings, which must be made suffi-
ciently strong to resist it. Loaded coal carts, furniture vans,
and such-like, all move from time to time with a wheel in the
gutter.

If the slots in the grating are of such width that they might
catch a wheel, it is necessary that they should be set transversely
(Fig. 86, the line of gutter being across the page). This makes it
impossible that a wheel can get between them. It is not often,
however, that this precaution is necessary with the modern
gratings, where the slots are much too narrow to form any
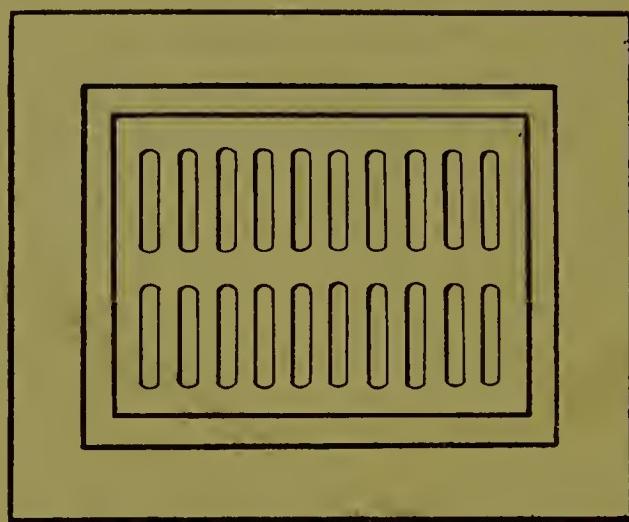
Fig. 86.—Gully Grating with Transverse Bars.

danger. It is then quite permissible to have the slots running
longitudinally (Fig. 87), and this has some advantage on steep
gradients, as the water is less likely to splash and leap over
them. The choice between the two is largely a matter of indi-
vidual preference.

The size of the openings should be liberal, as partial obstruc-
tion is not infrequent. A good deal of light rubbish is thrown
on the street surface : straw, dead leaves, waste paper, orange
and banana skins, etc., and a sharp shower carries these down the
gutter. They are very apt to become entangled in the grating,
and during such a shower few gratings remain perfectly clear.
It is desirable that each grating should have a considerable

margin of free opening beyond the size required to pass its full estimated allowance of rain-water, and it is necessary sometimes in places where a surface flood would cause serious mischief to provide a supplementary or relief gully. The longitudinal bars are perhaps less apt to catch rubbish than the transverse bars.

Outlet under Kerb.—In order to avoid gratings on the surface the opening may be made in the face of the kerb. This arrangement is sometimes called a " buddle-hole." Its advantage is that the hole may be made considerably larger than would
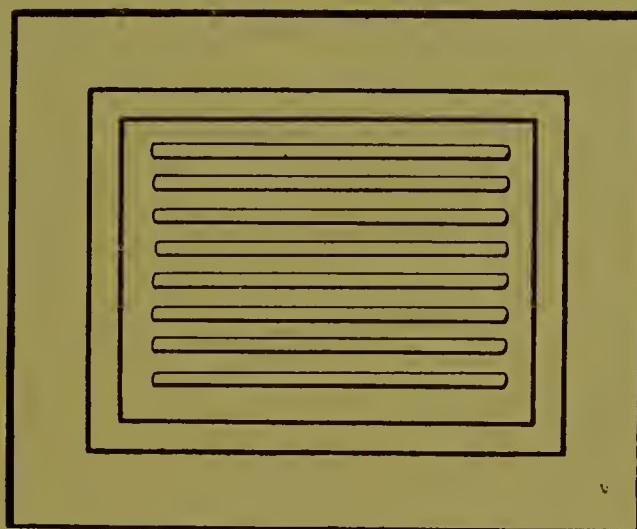
FIG. 87.—Gully Grating with Longitudinal Bars

otherwise be possible, without the need for a grating, and that the chance of obstruction is thus diminished. The large opening, however, has disadvantages of its own, and the system is not a very poular one.

Trapping.—When it was first thought that sewers needed ventilation the gullies in the gutters seemed a most convenient means of providing this. But it was soon realised that this was unsatisfactory, as smells from the sewer came up at an awkward place. It then became customary to trap these gullies, treating sewer ventilation as a separate problem (see Chapter X). Effective trapping requires some consideration, as the seal depends on the contained water, which gradually evaporates.

In a prolonged period of dry weather the trap will naturally dry up, unless it is replenished by street watering. In any case, it is desirable to diminish evaporation as much as possible, and to provide such a depth of seal that the trap may remain effective even after considerable loss of water. This requirement is closely associated with the next.

Silt Collection.—The water running off the street surface carries a large quantity of silt, whose character depends largely on the nature of the surface, but which it is not desirable to admit into the sewer. The gully, therefore, is combined with a catchpit to intercept this rubbish, as well as with a trap to keep back sewer gases. Baldwin Latham, in his well-known book on Sanitary Engineering, tells that one of the earliest gullies was modelled on the ordinary coffee-pot, and except for the tapering body a shape not very unlike this is still quite common. Fig. 88 shows the ordinary features of such a gully. The lower part of the body serves for the deposit of grit, which is scooped out from time to time by the scavengers, while the outlet—the equivalent of the spout—enters the body well below the water line, and is thus securely trapped. A handhole as shown is sometimes provided on the outlet side, but this is not an unmixed advantage, as the cover is apt to be left loose.
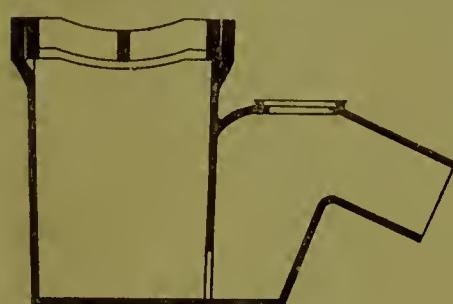
Fig. 88.—Gully of Ordinary Type.

Types of Gully.—From this elementary form numerous types have been evolved, each claiming special advantages. Among the numerous features which have been introduced, and many of which are or have been the subject of patents, the following may be mentioned :—

Facility for Removing Grit.—This in some cases takes the form of a movable box, which normally stands in the bottom of the

gully, and into which the grit drops. This is lifted out and emptied from time to time. Fig. 89 shows such a " mud box "

placed in a gully. This gully, while generally similar to that shown in Fig. 88, has an improved arrangement for access beyond the trap. In other cases the bottom is made hemispherical, or at least with rounded corners, so that the grit may be more efficiently taken out by means of a scoop.

Fig. 89.—Gully with Mud Box.

Security of Trapping.—This is disturbed in the ordinary gully by the operation of cleaning. When the grit pan is lifted out, or when the grit is ladled out, the water level in the receptacle
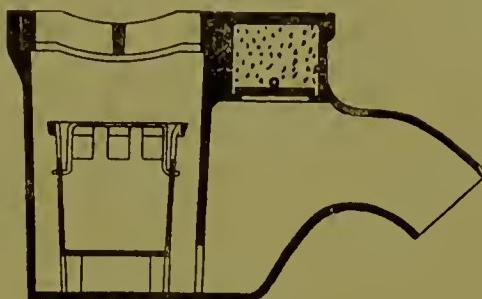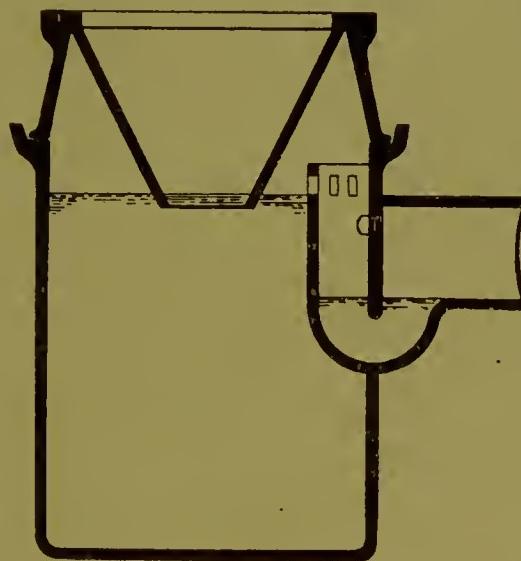
Fig. 90.—Crosta gully, Diagram.

necessarily falls, and it may come below the lip on which the seal depends. The efforts to prevent loss of seal in this way have taken the form usually of double trapping, combined with double chambering. In the Crosta gully, for example (shown diagrammatically in Fig. 90), the chamber is divided into

two compartments by a partition. The water which enters the first overflows into the second, which it leaves by an outlet of the coffee-pot type. Any cleaning of the receptacle affects only the first chamber, leaving the water in the second undisturbed.

Facility of Access to Outlet.—The ordinary type gives no such facility, and any obstruction which cannot be removed by working through the trap involves opening the surface and cutting into the outgo pipe. Many of the special types provide movable plugs, on the same principle as the cap of the " raking arm " of intercepting chambers. But the same objection which has somewhat clouded the reputation of the raking arm is encountered here. There is no doubt that the cap will be removed when an obstruction takes place ; there is very great doubt whether it will be replaced. If it is not, the whole elaborate arrangement for trapping becomes useless.

It is a question for consideration in each case whether it is worth while to employ any of the more elaborate contrivances ; or whether, especially in semi-rural districts, efficiency may be reached by the adoption of appliances which are the common property of every manufacturer who chooses to make them.

CHAPTER XIII

INVERTED SYPHONS

A DESIRABLE route for a sewer is sometimes intersected by an obstacle—such as a river, canal, or railway—through which the sewer cannot be taken at its proper level. If it were lowered sufficiently to pass under the obstruction without any provision for regaining its level the loss of elevation would in many cases be fatal to the whole scheme.

An "inverted syphon" may meet the difficulty. The sewer dips so as to get under the obstruction, and rises to its proper level after passing it. The syphon always stands full, and the sewage entering one end raises the level there and causes an overflow into the outgo sewer at the other end.

This is a very elementary application of hydraulic principles, and is the ordinary method adopted in water mains. There is nothing in the nature of syphonic action, the flow is the ordinary flow of water under pressure and the name " inverted syphon " merely describes the appearance of the arrangement. The principles involved are very similar to those involved in the working of sea outfall sewers.

Even in the case of a water main, carrying water which has a very small amount of suspended matter, provision is made for the removal of any deposit from the lower parts of the pipe. This is done by means of scour valves, which are placed at the bottom of each depression. By opening these valves occasionally, any deposit is driven out by the rush of water. In dealing with sewage the difficulty is greater because (1) there is much more suspended matter; (2) the flow is more irregular; (3) the deposit is of much more objectionable material; and (4) the lowest part of the syphon is usually so low that no drain from it is possible.

It is necessary to appreciate fully the difference between the flow in a syphon and that in an ordinary sewer. In each the liquid must move with sufficient velocity to prevent deposit, and in the ordinary sewer this is secured by having a sufficient gradient. The sewage runs through the sewer with a velocity which depends chiefly on the gradient and on the depth of flow. If one part of a sewer is steeper than another the sewage runs through that part more quickly, and the velocity at any part depends (practically) on the gradient of that particular part. In an inverted syphon the velocity depends not on the actual gradient of any part, but on the virtual gradient of the syphon as a whole, that is, the difference of level of the liquid surfaces at the two ends divided by the total length of the
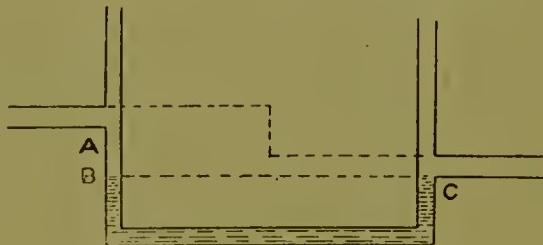
Fig. 91.—Inverted Syphon.

syphon. The amount of sewage passing one point is the same as that passing any other point in the syphon, and therefore if the sectional area of the syphon is the same throughout the velocity of the sewage must be the same throughout, even though at some parts it is moving uphill.

Fig. 91 shows such a syphon, where the sewage enters at A and leaves at C. The maximum length and the maximum difference in level are obviously fixed, but as the height to which the liquid stands at A and at C varies, the actual length and the actual difference in level vary also. The variation in length is trifling in proportion to the total length, and may in ordinary circumstances be neglected. The difference in level, on the other hand, varies greatly in proportion to its total amount.

Suppose that no sewage is entering the syphon. The liquid stands at the same level on both sides, B and C, as of course

anything above has flowed off into the outgoing sewer at C. There is no difference of level, no gradient, and no movement.

If a small flow comes in at A it falls on to the liquid at B, raises the level there, and so produces motion through the syphon and an overflow at C. But if the flow remains small the rise at B is very trifling.

If the flow becomes greater, the surface at B rises higher, and the surface at C also rises. If the incoming sewer at A, the syphon itself, and the outgoing sewer at C, are all properly proportioned, the maximum flow of sewage will just fill the incoming sewer to A[1] and the outgoing sewer to C[1] (Fig. 92). It should be noted that these two figures are merely diagrams. It will be seen from what follows that any such design would be a bad one.
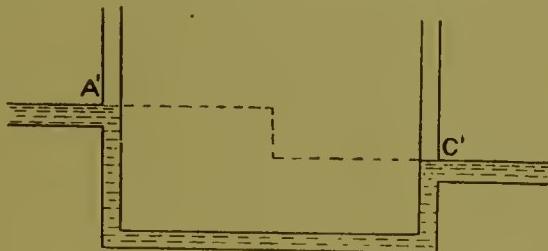
FIG. 92.—Inverted Syphon, Maximum Flow.

The difference in level between A and C thus varies with the amount of flow, and the velocity of flow through the syphon varies with this difference of level. The velocity in the syphon may be very different from that in the sewer on either side.

When an ordinary sewer is discharging less than its full capacity it runs only partially full, and the difference in volume discharged is due more to the smaller sectional area of liquid than to any diminution of velocity. There may be great varia- tion in volume with comparatively little variation in velocity. But as a syphon is always running full, and there can be no change in the sectional area of the liquid, the change must be altogether in the velocity.

If, therefore, a syphon is made of the same sectional area as the sewers with which it connects, its velocity in times of heavy flow will be somewhat less than that of the sewer, and in times of trifling flow it will be greatly less. If the velocity in the sewer

is merely that which is needed to prevent deposit, the syphon velocity will be far too small.

If this difficulty is got over by making the syphon of smaller sectional area, then the maximum velocity in the syphon must be proportionately greater than the maximum velocity in the sewer, and sufficient difference in level must be provided to give that velocity.

It is necessary to ascertain (1) the length of the syphon, including any allowance for bends (see p. 148) ; (2) the maximum head which can be given, after deducting unavoidable losses ; and (3) the maximum amount of liquid which the syphon will be called on to convey. The virtual gradient with that length and head is ascertained, and the diameter is chosen which will carry the maximum quantity of liquid with the velocity due to that gradient.

Take, for example, a syphon whose length is to be about 300 feet, which must be capable of passing 150,000 gallons per hour, and where the maximum head available (A ^{1} to C ^{1} in Fig. 92) is 3 feet. The virtual gradient when running to its full capacity is thus 1 in 100. A reference to the table on p. 37 will show that at this gradient a pipe of 15 inches diameter will carry just about the required quantity, and that size of pipe therefore would appear to be suitab'e. Its velocity with maximum discharge would be nearly 6 feet per second, which is satisfactory.

This, however, involves two assumptions. One is that the inside of the syphon is free from any deposit or incrustation which would retard the flow, and as there is more risk of deposit in a syphon than in an ordinary sewer, it would be well to assume that the velocity and the discharge might be rather less. If the roughness coefficient were taken as ·013, instead of ·012, the velocity would be about 5 feet per second and the discharge about 140,000 gallons per hour. The other assumption is that the sewage already has the necessary velocity : if not, a head of nearly six inches would be used up in producing the velocity, and the virtual gradient would be correspondingly less. This is discussed more fully in the succeeding paragraphs.

The normal flow must be also considered, and the normal velocity will bear the same relation to the maximum velocity that

the normal does to its maximum flow. Assuming that the maximum flow is six times the normal, it follows that the normal velocity is only one-sixth of the maximum, or barely one foot per second. As the " normal " is the average of twenty-four hours it is evident that the velocity at some parts of the day will be very low indeed.

In the case of such a syphon, where the velocity fluctuates much more sharply than in an ordinary sewer, it is fair to set the greater maximum velocity against any deficiency in the minimum, and so a syphon is not to be condemned because its velocity is not such as to be self-cleansing in dry weather. A syphon is a part of any sewerage system that requires special attention in any event, and part of that attention may reasonably be given to keeping it clean mechanically when the weather renders that necessary. In dry weather the use of a rope as described below might be necessary.

Duplicate Pipes.—The difficulty, however, may be reduced by having the syphon in duplicate, each pipe of course smaller than the single pipe would be. In dry weather the whole flow can be sent through the one syphon, in which therefore the velocity is greater than it would be in a single large pipe. A convenient arrangement is to have the inlet chamber so designed that while the flow can be sent through either or both pipes at will, the sluices can be so set that the flow up to a certain volume will all go through the one ; when this volume is exceeded the other also comes automatically into operation ; and, finally, a storm overflow takes to the river anything in excess of the combined capacity.

Referring to the example just given, where 15 inches was indicated as the suitable size for a single pipe, it will be seen by reference to the table that two 12-inch pipes would give rather more than the same carrying capacity. The 15-inch pipe might, therefore, safely be replaced by two 12-inch pipes. While the maximum discharge would be slightly greater, the minimum velocity (assuming one pipe only to be in operation) would be almost double the minimum given by the single pipe.

It is not in such a case essential that the two pipes should be

of the same diameter. In the case of a flow which was subject to great variation it would be quite proper to have a smaller pipe for ordinary working and a larger one as a " relief " pipe.

In most cases the extra cost of duplicating the syphon will not be great in proportion to the total cost. A large proportion of

Fig. 93.—Inverted Syphon following Natural Contour.

the total is for general and preparatory work which is little, if at all, increased by the second pipe.

The duplicate pipe has the further advantage that it gives better facilities for cleaning when this is needed (see p. 152).

Bends.—It was mentioned (p. 146) that any allowance for bends should be included in the length of the syphon as used for calculation : that is, that the length should be assumed to be greater than the actual length by any such allowance as might
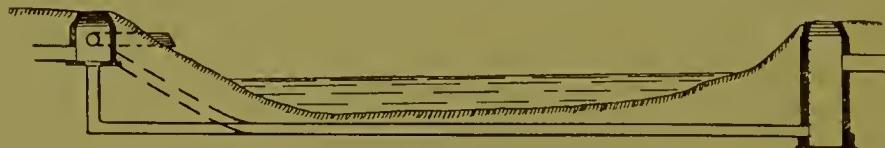
Fig. 94.—Inverted Syphon with Vertical Pit.

be necessary. There is no very satisfactory method of calculating the required allowance, and anything like precision is impracticable. The question is complicated also by the fact that in any given syphon the necessary changes of direction may be made not by actual bends but by pits, or by a combination, as in Figs. 93 and 94.

With regard to actual bends, it may be said that when the syphon is long their effect is small. The effect of a bend or bends is usually and conveniently expressed as an addition to the length of the pipe, and as a short syphon is likely to have

as many bends as a long one, the proportionate addition is much greater. From a table given by Schoder (*Proc. Amer. Soc. C.E.*, Vol. XXXIV, p. 416) from experiments on 6-inch pipes, it would appear that if the radius of the bend (measured on its axis) is anything between 1·76 and 15 diameters of the pipe itself, the additional length due to the effect of a 90° bend will not exceed 6 or 7 feet, and may be less than half that amount, for velocities of from 3 to 16 feet per second. Taking the example given, of a pipe 300 feet long, with a possible head of 3 feet, the addition of, say, 12 feet to allow for two right-angled bends (or a larger number making up two right angles in all) would only reduce the virtual gradient from 1 in 100 to 1 in 104, which would be more than covered by the general allowances which would be made. But if the total length were, say, 50, and the total fall 1 foot, then the same addition would reduce the gradient from 1 in 50 to 1 in 62, a much more important difference. From the curves given by Dr. Brightmore (*Proc. Inst. C.E.*, Vol. CLXIX, p. 327) from experiments on 3-inch and 4-inch pipes, it would appear further that the loss of head due to a bend does not diminish continuously as the radius of the bend increases. (Figs. 91 and 92, which show square corners or " knees " are purely diagrammatic.) There are, however, many factors whose effect cannot be exactly estimated, and it is quite impossible with our present knowledge to make any calculations which are even very nearly precise. Most syphons, for example, are of considerably greater diameter than the pipes on which these experiments were made. The allowance for bends is one of the very numerous engineering problems where, after making such allowances as seem reasonable in the light of our knowledge, the common sense and experience of the engineer must be applied to judge whether any special margin is demanded by the circumstances of the case. If the temporary insufficiency of the syphon to cope with a flood would produce serious damage, then all the worst possibilities must be allowed for : if, on the other hand, no particular damage would be done, then the allowances might properly be taken at the minimum, so as to get the undoubted advantages of a smaller syphon.

Vertical Ends.—If the syphon consists of two vertical ends, with a pipe between the two which is practically horizontal (which might be a very convenient form of construction) the loss of head due to inertia may be of serious consequence. This will be understood by reference to the diagrammatic figures 91 or 92, where it will be seen that the water has to take four turns, and in no case has it on reaching the bend any velocity in the required direction. It would appear that there is thus at each corner a loss of head equal to that required to give it the velocity in the new direction, $\frac{v^2}{2g}$. Assuming the pipe to be of the same diameter throughout, including the delivery end from the rising leg of the syphon, the full velocity has to be given to the water at four different places. Even with the moderate velocity of 6 feet per second, the head lost would be $4\frac{6^2}{2g} = 4 \times \frac{36}{64}$, or fully 2 feet. But this is only a rough approximation, and the matter is much more complex, as Dr. Brightmore's paper shows.

This loss, whatever its amount, might be diminished in various ways. If the intake end were in the form of a pit, it would no doubt be of greater area than the horizontal pipe. If it were twice the area the velocity in it would only be one-half the syphon velocity, and the loss at that point would be divided by four (the square of the reduction in velocity). The loss on entering the horizontal pipe would remain, and unless care were taken to provide a bell-mouthed entrance it might be increased. The loss on entering the rising leg might be reduced just as that on entering the descending leg might be reduced, by increasing its area and thus reducing the velocity : while the loss on leaving the rising leg might be reduced by giving a long sill with an overfall into a large pipe, so that a comparatively small velocity at this part would be enough to keep the syphon free. Altogether, it might be estimated that the total loss might be kept down to that due to one and a half or two bends, instead of four—that is, again taking six feet per second, and accepting the above calculation as being roughly correct, the loss of head might be 10 or 12 inches instead of fully 2 feet. As these losses increase with the

square of the velocity, they become very serious when a high velocity is required.

Contour.—A contour similar to that shown in Fig. 93 is for some reasons the best. It follows approximately the natural contour of the river-bed, and as it avoids any sharp bends the loss of head is reduced to a minimum. On the other hand, it is sometimes more convenient for structural reasons to have the ends in the form of manholes, and the possibility of deposit must not be overlooked. Any deposit taking place in a syphon like Fig. 93 would be at a most inaccessible place, and would involve considerable difficulty in dealing with it. By making a manhole at each end, or even at one end, as shown in Fig. 94, the tendency to deposit is no doubt increased, but such deposit as does take place is at a part from which it can readily be removed. The loss of head is considerably increased by the vertical ends, but this might be minimised by forming the intake end as shown by the dotted lines, thus utilising the velocity of approach to give the velocity in the pipe.

Maximum required Capacity.—As a rule the total flow through the syphon can be limited to a fixed quantity, the remainder being discharged elsewhere. But it must be borne in mind that unless a storm overflow can be provided the syphon itself must be able to take off the largest possible flow. The necessary size is not always easy to determine : a syphon which deals with the rain-water from a small area has to be designed in view of the intense local rainfall due to a thunderstorm or " cloud-burst," while over a large area the local intensity will not be so great. Fortunately, when a syphon is designed to take away all the possible flow, it almost invariably happens that it supersedes some existing watercourse, and the test of the sufficiency of the syphon is its capacity for dealing with all the water which the unaltered part of the channel can bring down to it. If damage were caused by flooding which was apparently traceable to the syphon, and legal proceedings followed, it is almost certain that the point at issue would be whether or not the carrying capacity of the syphon was less than that of the watercourse immediately

above and below. From what has already been said, it will be clear that equal carrying capacity does not necessarily require equal area.*

Screening.—It is important that no objects of large size should be allowed to enter the syphon, and it may be necessary that the sewage before entering it should pass through screens of suitable aperture. But unless these screens are carefully and regularly attended to, they may be a source of danger rather than of safety, as a choked screen may be a very complete obstruction. Easy access to the screens (especially in front), and proper facilities for removing any debris are essential.

Cleaning a Syphon.—If there is a lower level into which the scour may discharge even occasionally, scour valves are provided at the lowest part of the syphon. But when the syphon level is too low for that, as it usually is when passing under a river-bed, then an arrangement of catchpits as shown in Fig. 94 (at both ends or only at the outlet end), from which the deposit is removed by dredging, is generally adopted. In order to stir up any sludge which may gather elsewhere, and ensure that it will be carried on to the catchpit, it is not uncommon to have a rope (made of copper wire to avoid corrosion) laid permanently through the syphon. This can be pulled backward and forward, either by itself or with some brushing arrangement attached to it.

Partial Syphon.—It is sometimes convenient to construct a sewer with a very flat gradient following on a steep one, although

* A very interesting decision was given in Glasgow in 1899 by Sheriff Guthrie. (Stewart v. Corporation of Glasgow and Caledonian Railway Company.) The pursuers claimed against the two defenders on the ground that a natural watercourse, the Camlachie Burn, had been replaced by an inverted syphon (constructed by the Railway Company with the approval of the Corporation) said to be of less capacity than the natural channel. A long and elaborate proof resulted in a decision that while the area of the new channel was smaller than that of the old, its carrying capacity was not. The pursuers therefore failed in this contention, although they succeeded against the Railway Company on account of a screen or grating which was held to have been improperly placed.

no part actually has a reverse gradient. The flow of sewage will naturally be rapid down the steep gradient, and slow along the flat part. There is a tendency, therefore, for the sewage to head itself up in the steep part, thus bringing pressure on the flat part, or for the flow in the flat part to become so slow that deposit will result. Unless proper provision is made, either of these may be disastrous.

But if the flat part, and a sufficient length of the steep part, are made suitable to resist pressure, and properly proportioned as to size, the fall in the steep part may be usefully employed. A sewer whose longitudinal section is as in Fig. 95 has a much greater carrying capacity from A to B than from B to C, if the
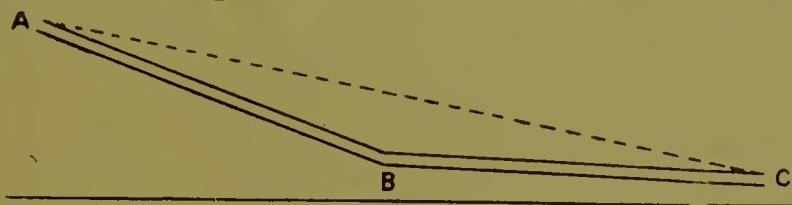
FIG. 95.—Virtual Gradient or Partial Syphon.

sectional area remains the same throughout and if no part is running under pressure : if the carrying capacity is made equal by making BC of larger area, then the velocity is too small to avoid deposit. But if the whole sewer from A to C is made of such area that it can deal with the maximum flow with the head from A to C, and of such material that it can stand the internal pressure, the action will be practically that of an inverted syphon. Comparatively small iron or steel tubes take the place of a large sewer, and the storm overflow is placed at A. In such a case of course junctions to this section of sewer are only permissible if sewage may safely head back in them to the hydraulic gradient (practically the line joining A and C on the section) at the point of junction, and any branches should be provided with an outlet for overflow water at a sufficiently low level to avoid damage.

Material.—Cast iron or steel will be used, as the syphon works constantly under pressure. The greater thickness of cast iron may give a longer life as against corrosion ; but steel is much

lighter and thus more easily handled, is more flexible, and has fewer joints. Lap-welded and weldless steel tubes are convenient for syphons of moderate diameter. The relative cost of iron and steel is variable, roughly it may be said that usually there is not much difference between the cost of cast iron and steel tubes (length for length), each at the makers' works : but transport and putting in place will probably be in favour of steel.

Example.—In Fig. 96 is shown an inverted syphon, in conjunction with an air lift (see Chapter XIV) designed by the author for the town of Crieff. On the sewer route the valley of the River Earn had to be crossed, though not under the river, and a few houses in the low part had to be drained. The crossing was effected by a double inverted syphon laid chiefly under the bridge footpath, and the manhole into which the syphon discharged received also the sewage forced up from the low area. This low-level sewage drained by gravitation into a sump at C, and from that was forced up by an Adams' " Autaram," as described in the next chapter.

Reference Table

A		Main Sewer entering Syphon
B		Main Sewer leaving Syphon
C		Forcing Chamber for Low Level Sewage
D		Air Compressing Tanks
AB		Double Syphon
CB		Rising Sewer from Forcing Chamber
DC		Pipe conveying Compressed Air
AE		Storm Overflow
FC		Gravitation Sewer to Forcing Chamber
FB		Gravitation Sewer to Outlet Manhole
CG		Overflow from Forcing Chamber
H		Scour Valves and Discharge Pipes
		Hatch Box Manholes

RIVER EARN

Plan of Syphon

Scale

Ft. 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 Ft.

River Earn

Section of Syphon.
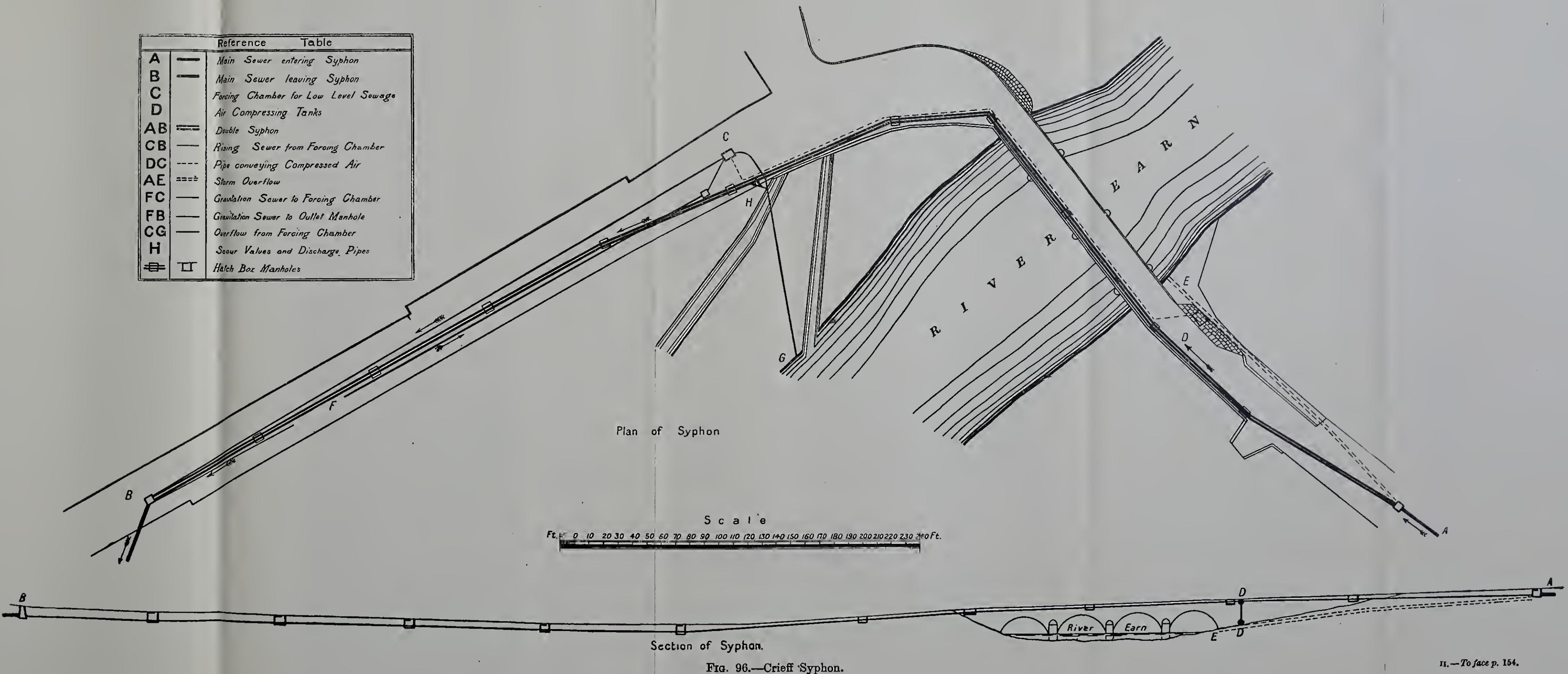
FIG. 96.—Crieff Syphon.
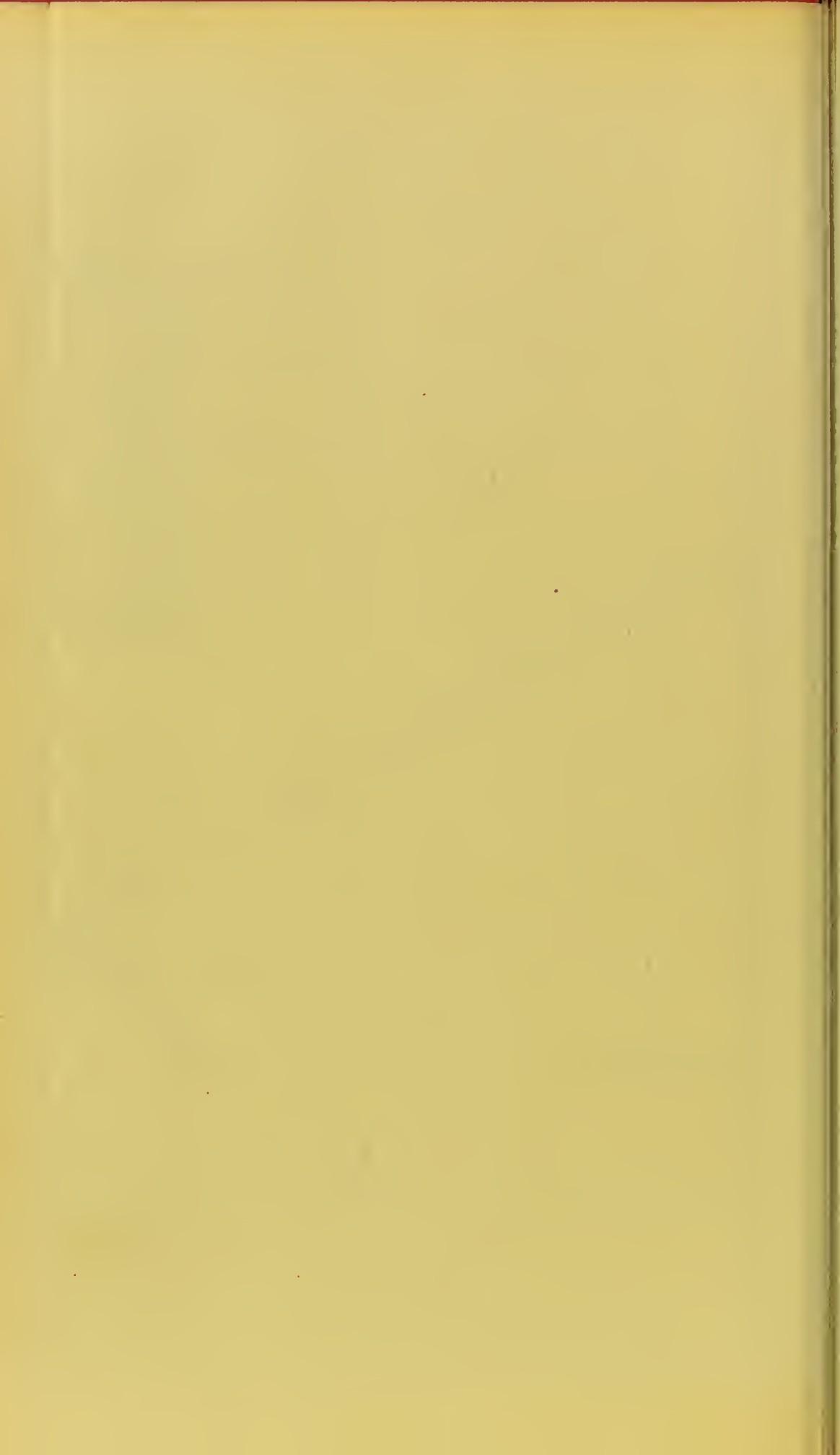
CHAPTER XIV

RAISING SEWAGE

To deal with this subject completely would involve considerations quite outside the scope of this volume. Where pumping has to be done on a large scale special expert knowledge is called for ; and while the sewerage engineer provides means for bringing the sewage to and from the pumping station, and possibly the necessary tanks, wells, and housing for the pumping machinery, the design of engines, boilers, pumps, and any other machinery should be in the hands of a competent mechanical engineer.

Mechanical Efficiency v. Convenience.—When a large volume of sewage is to be raised, the question of mechanical efficiency is most important. The engineer aims at getting the utmost possible " duty " from the fuel consumed, and any failure in this respect is serious. Once it is decided that the sewage must be brought to a large pumping station, the responsibility for its effective treatment there should rest on a man who is thoroughly conversant with every detail of pumping machinery, although of course he should be in close touch with the man who designs the sewers. The latter is not expected to be an expert in pumping.

On the other hand, it often happens that a comparatively small part of the sewage needs to be raised, and that the total power needed is trifling. In that case mechanical efficiency may be of small consequence as compared with convenience of application. If, for instance, there is a method which allows the power to be generated at some convenient centre and transmitted to several places where it is required, it may be much more economical to do this than to provide generators at each of the places, even if there is great loss in the transmission. Still further, if a source of power which would otherwise be

wasted, such as the fall of water or of sewage itself, can be used, it matters little though the mechanical efficiency of the apparatus for using it may be poor.

The question turns altogether, or nearly so, on the magnitude of the work to be done at any particular place. A large town which has to lift any considerable proportion of its sewage will concentrate the work at one place and construct a completely equipped pumping station, with machinery to give the utmost efficiency in working : a small quantity of sewage, or several small quantities here and there, will be lifted by any effective method which will give the least trouble and need for skilled management, irrespective of its purely mechanical merits.

It is with the latter class of problem that this chapter deals, as the sewerage engineer is expected to be able to solve it.

Small Lifting Stations.—The arrangement of these depends on :—
1. The number of places at which sewage is to be raised.
2. The quantity of sewage at each.
3. The height of lift at each.
4. The power available.

Source of Power.—If the low-level sewage can be conveniently collected at one place, and there raised to the required higher level, there is a considerable choice of method. Steam power, which has much in its favour for large schemes, is out of the question, as the necessity for constant skilled attendance over-balances any extra efficiency of the apparatus. Where reliable intermittent attention is readily available, gas or oil engines (including petrol and the like, if not barred by the cost) may be used as motive power : the former if supplied by town gas will work steadily and for considerable periods without attention. Suction gas requires more attention. Oil engines of the ordinary type need little skill to run them : Diesel engines, on the other hand, are less suitable for unskilled management. If electric power is available, it forms a very convenient and readily applied source of power, and will probably be preferred if it can be got at a sufficiently low price. If the town water supply is

liberal and under a good pressure, a water-driven pump may be quite an economical method of working.

Conveyance of Power.—When the power must be generated at a distance from its point of application, either because there are more lifts than one or because there is no convenient place for its generation where it is wanted, there are two methods of transmission which might be considered. These are :—
1. Compressed air.
2. Electricity.
(The hydraulic method is not so generally applicable.)

Compressed Air.—This was brought into prominence by the invention of Shone's Ejector (described later) the chief advantage of which was that it enabled the power for any number of detached lifts to be generated at one place, and conveyed by pipes to the place required, there to be used with practically no machinery. It is not as a rule economical to use this method of transmission unless the sewage is to be lifted at more than one place. A later invention was Adams's "Autaram," which, instead of requiring a special outside source of power, used the fall of water or of sewage which would otherwise have run to waste. The general principle of these two appliances is identical so far as the application of the power goes. The latter, however, is less dependent on economy of power, as its power costs nothing beyond the installation of the machinery, and it is, therefore, readily applicable to a single station.

Electricity.—This is a very convenient means of applying power, either got from mains provided for general purposes, or generated for sewage lifting at some convenient place. It is easy to arrange a float control, by which the current is switched on when the sewage rises to a certain height in a tank, and switched off when by the action of the pump it has been sufficiently lowered. The apparatus required is more complicated and delicate than that required for working by compressed air, but, on the other hand, it is easier to convey power to a distance electrically than by any other means.

Electrical transmission of power is a much more formidable rival now than in the early days of the Shone Ejector, and should always be considered. The Hon. R. C. Parsons (*Proc. Inst. C.E.*, Vol. CCVIII) made a very interesting analysis of the various methods of raising sewage in connection with the drainage of the town of Buenos Aires, with special reference to the Stereophagus Pump, mentioned below, of which he was the inventor, and his figures indicated a substantial financial advantage in favour of pumping.

Humphrey's Pump.—This recent application of the principle of the internal combustion engine is sometimes useful for sewage lifting. Instead of acting by means of a cylinder and piston and then by a pump, the pressure generated by the combustion of the gases is applied direct to the liquid surface, thus forcing it up through the required pipes.

Form of Pump.—When direct pumping is employed, the form of pump is usually centrifugal, unless the lift is high. For a high lift, and consequently against a heavy pressure, the plunger type is more usual. A valuable development of the centrifugal pump is the " Stereophagus," where the blades are shaped in such a way that any hard, fibrous, or other obstructive substance is gradually cut to pieces. This pump will deal without difficulty with substances which would choke any pump of the ordinary type.

Shone's Ejector.—This was the pioneer system of sewage raising in detached areas, and its principle is that air is compressed by suitable machinery at a central station, and conveyed by pipes to the places at which it is required. The air-compressors are driven by any suitable motor, and may be located at some place where skilled attendance is already necessary—gasworks, water pumping station, or the like. There is thus greater latitude in choice, and it may be that steam from boilers needed for another purpose may be available. The generation of sufficient power at one point to supply compressed air at several, is much more economical than the independent generation of power at each point.

Fig. 97 shows the ejector (as made by Messrs. Hughes and Lancaster) and its working is as follows : The low-level sewer pours the sewage into the ejector at A, where there is a valve
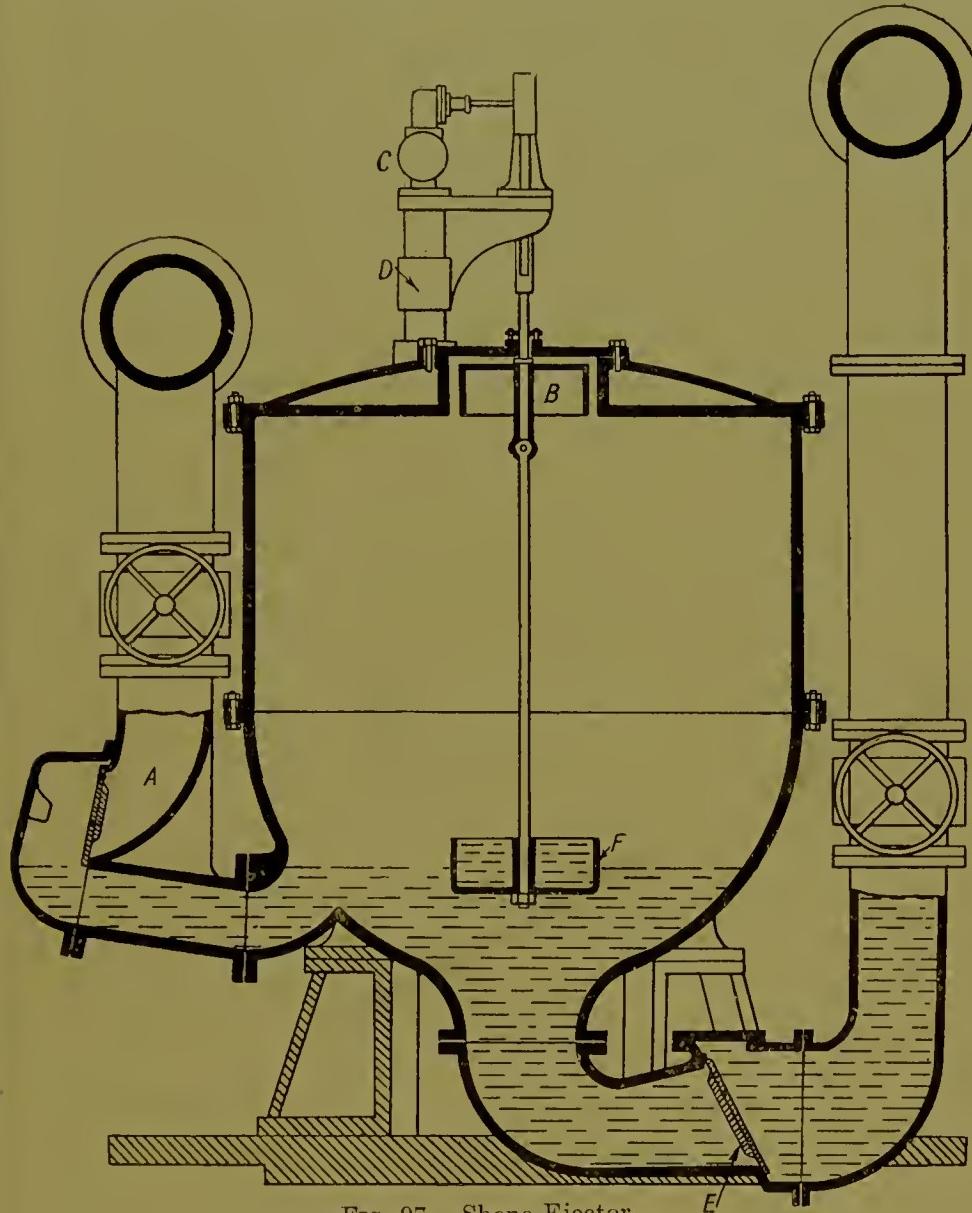
FIG. 97.—Shone Ejector.

permitting the flow in one direction only. Inside the ejector there is a stem carrying two cups (the upper one inverted), and passing through the cover to an air valve. While the sewage is flowing in, that valve is open to the outer air and

the air in the ejector is driven out by the rise of the sewage. But when the liquid surface has reached the lip of the inverted cup, B, the air inside that cup is compressed and tends to push the rod upward. As the liquid rises the lifting power increases, and the rod is forced upward. The weight of the cups and rod is trifling when they are completely immersed, and does not prevent the lifting action. The rise of the rod turns the valve C, shutting off the communication with the open air, and putting the upper part of the ejector into communication instead with the compressed air conveyed by the pipe D. The air is thus admitted to press on the surface of the contained sewage, which is pressed down. The sewage cannot return past the valve A and so flows up the rising main (through another non-return valve E), and is delivered into the high level sewer. The air pressure of course must be sufficient to overcome the head of liquid in the rising main. When by the action of the air the liquid in the ejector falls to the level of the lower cup F, the liquid contained in this cup can fall no further, and as the surrounding liquid continues to fall, the contents of the cup become a heavy unbalanced load on the spindle, which is thus pulled down. The valve is again reversed : the compressed air is allowed to escape, and sewage again flows in. The contents of the rising main are prevented from returning to the ejector by the valve E. In the figure the discharge is almost complete, and the rod and cups, though still at the highest position, are on the point of being pulled down.

It will be observed that the action is intermittent, and that if there should only be one ejector the sewage will accumulate in the sewer during the time that it is being emptied. For this reason it is usually found best to have the ejectors arranged in batteries of two or more, so that when one is not receiving sewage it may flow into another.

The convenience of the arrangement is clearly very great, and may often be sufficient to outweigh its obvious low mechanical efficiency. Apart from all losses of transmission, there is a loss of head both at entrance and exit. The ejector must be set so much below the invert of the incoming or low-level sewer that the sewage will fill the ejector by gravitation, and the lift is from

the bottom of the ejector to the highest water level of the high-level sewer. There is thus an addition of a considerable amount to the net lift, and if the net lift is small the addition (which cannot be varied much) may be a very substantial proportion of the whole. The system is, therefore, not economical in a mechanical sense, but its convenience and simplicity are often quite great enough to justify its use. The greater the number of lifts which can be served from one central station the greater is the practical economy.

The whole of the lifting apparatus may be put underground and is often installed under streets. There are no moving parts with the exception of the valve and the spindle, and there is no great noise in the action. The sewage flows smoothly into and out of the ejector, and there is no churning to give off offensive odours. It may be installed with confidence whenever the engineer's calculations show that it is in the interest of economy to do so.

Adams's " Autaram."—This is one of the most ingenious of sewerage appliances. The principle is exactly that of the scientific toy known as " Hero's Fountain." When two double-necked (Wolff's) bottles, A and B, are arranged as in Fig. 98, A nearly filled with water and B nearly filled with air, and when water is poured into B through a tube C, the air in the bottle is compressed by the weight of the water. By the connecting tube D the compressed air is conveyed to the other bottle A, and acts there on the surface of the water, which is thus forced up the tube E which dips nearly to the bottom. If this tube is finished with a nozzle, the water is

FIG. 98.—Hero's Fountain.

delivered in the form of a fountain jet : if it is taken up as shown the water can be delivered to any height less than the head in the other bottle.

M.S.E.—II.—M
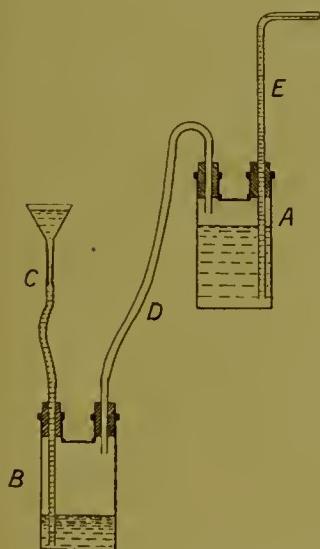
In this elementary apparatus, it is necessary to empty the one bottle and to fill the other from time to time, and in order that these operations may go on repeatedly and steadily various additions have to be made. The actual working apparatus as designed by Mr. Adams is shown in skeleton form in Fig. 99. The sewage from the low-level sewer gathers in the tank A, from which it passes through a non-return valve to the cylinder B. The delivery pipe C goes to the high-level sewer. The air pressure is brought by the pipe D from the cylinder E, the pressure being generated by the descent of water from the tank F. This tank is fed with water or sewage, the former, of course, being preferable when it is available. The apparatus has often been installed, however, in places where the driving power was obtained from sewage which could be allowed to fall from a high level to an intermediate level, thereby lifting sewage from a low level to the intermediate level. The working liquid, whether water or sewage, enters the tank, and when this is full the contents are discharged by a syphon down the pipe into the cylinder E. The air, compressed in this cylinder, is transferred by the air pipe D to the cylinder B, which has meantime been filling with sewage. The pressure of air sends the sewage from B into the high-level sewer through the rising main C. The cylinder E is now full of sewage (or of water), and this is drawn off by the syphon G, which has been charged by the delivery from F through the cylinder. The whole apparatus is ready for another lift when that has been accomplished, the tank F having meantime been collecting more driving liquid, and the tank B more sewage to be raised.

The limitations of the apparatus are (1) the driving liquid must be greater in volume that the sewage to be lifted. In practice, in order to allow for the compression of the air, an excess of about 150 per cent is desirable. (2) The fall of the driving liquid must be greater than the *gross* lift required—that is, not only from invert to invert of the two sewers, but from the bottom of the tank B to the water level of the high-level sewer. An excess of about 50 p er cent is sufficient. As in the Shone system, the mechanical efficiency is low, but in spite of that the apparatus is often very useful. In a hilly district it is not unusual

to find that a sewer has far more fall than is needed, while at another place sewage may need to be lifted. The fall of the higher sewage may be used to work the lift and thereby raise the other.
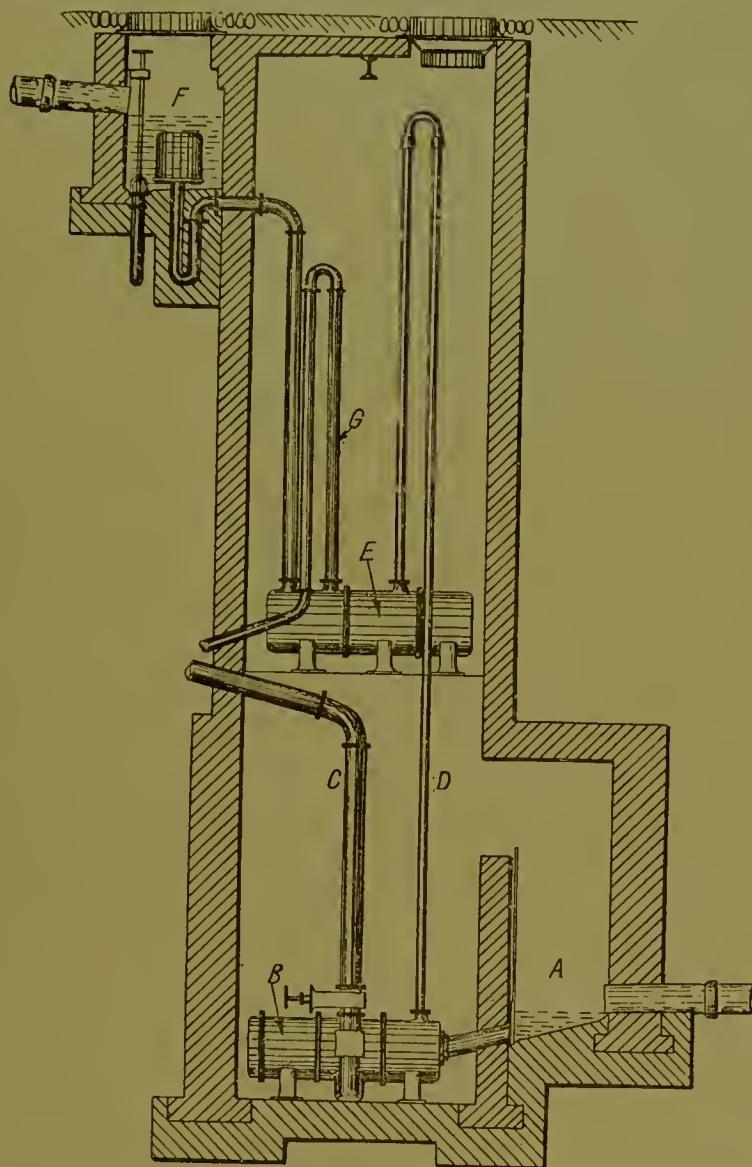
Fig. 99.—Adams's "Autaram."

Still better is the case when some flow of clean or at least clear water can be used for this purpose, as not only is the apparatus less likely to require attention, but the driving water may be discharged direct into a stream, possibly at a level much

below that of the sewers. The author had an excellent example of this in the sewerage system of Crieff, where the sewage from a low-lying part is raised by the flow from some disused springs, supplemented by the drainage from a deep railway cutting. The tank which collects the water is set on a bridge abutment, and the used water goes direct to the river. In such a case as this, there is no need for any relation between the height of the cylinders B and E. So long as means exist for draining the former, it is of no consequence whether it is lower or higher than the other. This is clearly seen by reference to Fig. 98. The connection is by a flexible tube, and the apparatus is equally efficient when A is on a table and B is on the floor as when the positions are reversed.

In a case where a supply of otherwise useless water is available in ordinary weather, but where in dry weather it may run short, it may be quite proper to draw on the town mains for the time being, assuming that there is an adequate supply. The volume of sewage in such circumstances is small, being merely the consumption of water for that particular district, and the quantity of water required may not be a serious matter. Very often also it is not necessary to provide any emergency plant, the discharge in time of emergency being direct to the stream.

Duplication of Plant.—In every case where any cessation of work would have serious consequences, it is essential that the plant should be in duplicate. If, on the other hand, the result would be that the sewage would flow into a stream of considerable size, where pollution by a small proportion of the sewage of the district would be no more than unsightly, it may be reasonable to dispense with this somewhat costly precaution. Every case must be decided on its own merits, and sometimes there may be considerations other than engineering to affect the conclusion. For example, a town or district which had been forced at the point of the bayonet to carry out purification works could scarcely expect much consideration at the hands of those who had enforced the works, if from time to time parts of them were non-effective.

CHAPTER XV

THE quantity of sewage to be provided for in the sewers has already been discussed (see Chapter III), and the method of effecting the required limitation has now to be considered. This, and the possibility of effecting it, will vary with each individual sewer.

Branch Sewers.—In the outlying branch sewers there can be no limitation of the flow. Everything in the shape of either sewage or rain-water must be accepted and carried down, unless of course there is a duplicate system.

Main Intercepting Sewer.—This collects the sewage which is brought down by the branch sewers, and it is usually at the entrance to this sewer that the separation between sewage and storm water takes place. When an " intercepting " sewer is constructed the sewer which previously took all the liquid to the natural watercourse is available to carry the storm water, and it is then convenient to make any required separation.

Methods of Separation.—The object is to allow a certain flow to pass into the sewerage system and so to the disposal works, while everything in excess of that goes into the natural watercourses. A number of methods are available, although no method has yet been devised which will effect the separation with anything like accuracy.

Pipes through Manhole Walls.—This method is the simplest, and is often used in small works. It is quite incapable of making any accurate separation, but is very useful in preventing flooding. It is illustrated in Fig. 100.

The pipe entering the manhole may be of larger size than the sewer pipe which leaves it, or it may have a larger carrying capacity due to its steeper gradient, or there may be more than one. If the case is that of a new intercepting sewer the old pipe will be available as an overflow. So long as the sewage enters the manhole in small quantity, it flows off by the new channel ; but as the quantity increases this channel becomes insufficient, and the water rises in the manhole. Ultimately it reaches the level of the old pipe and begins to escape there, but it will be observed that even after it has reached the invert of that pipe very little enters it. It is only when the water rises considerably higher that any large proportion enters this pipe, and meantime the pressure on the lower pipe is increasing. If, therefore, the sizes and levels are so adjusted that the required quantity of water is passing into the lower pipe just as the water surface has reached the invert of the upper pipe, it is evident that much more will enter when the upper pipe is running full, and still more when the upper pipe is running under pressure. This variation can be diminished, although not entirely obviated, by making the inlet to the upper pipe in the form of a horizontal sill, the longer the better.

Fig. 100.—Storm Overflow, Pipe through Manhole Wall.

It is to be noticed that a storm overflow, leaving the manhole at a higher level than the top of the sewer, is clear evidence that the sewer will sometimes run under pressure. This may sometimes have awkward consequences. In a case in which the author was concerned, a claim was made against a local authority by a proprietor, the allegation being that an underground heating chamber was from time to time flooded with sewage (or a mixture of sewage and water) from an adjoining sewer. The flooding was undoubted, but it was denied that it came from the sewer, and among other things, it was pointed out that the

water rose higher than the top of the sewer. This at first seemed to prove conclusively that the origin was other than the sewer, but it was found that in a neighbouring manhole there was a storm overflow of the kind under consideration, several feet above the top of the sewer. It was found further that this had been put in on account of flooding elsewhere, and that it had been an effectual remedy. The conclusion was obvious that the liquid rose in the manhole from time to time to such a height as to escape from the overflow, and that therefore the sewer at that point was running under pressure. This discovery deprived the defenders of what was otherwise a strong argument, and the decision went against them.

Side Weir.—When the two outlets are at approximately the same level, a side weir or sill is often used (Fig. 101). This is better than the method just described, as it gives a longer sill at a uniform (or even a falling) level, but within any reasonable limits of length it is far from being a true measure of quantity. The rise of water which produces the overfall not only gives a greater sectional area in the channel, but it adds very materially to the velocity of flow. On a large scale it has been improved

Fig. 101.—Storm Overflow, Side Weir.

by being made double, the sill being on both sides : and further, by a gradual diminution of the hydraulic mean depth. This was done in the Glasgow Main Outfall Sewer.

Side Weir on Curve.—Another development of the side weir is to construct it on a curve, so that the velocity of approach tends to carry the surplus over the weir, while the normal quantity is retained by the walls of the channel. This method was described by Mr. J. Corbett (*Proc. Inst. C.E.*, CLXIV, p. 97)

who pointed out that it was better to divert from the straight line the comparatively small volume of normal sewage and to leave the large volume of storm water to go straight on. There is no doubt that this method of using the velocity of approach and the inertia to assist the separation will give a much greater accuracy of separation than the reverse method. The principle is illustrated in Fig. 102.
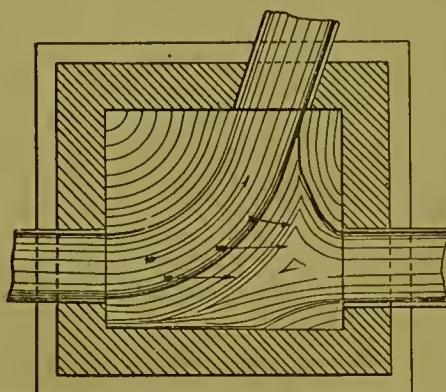
FIG. 102.—Storm Overflow, Side Weir on Curve.

Deflecting Plate.—In a paper on " The Elimination of Storm Water from Sewerage Systems," read before the Institution of Civil Engineers (*Proc.* CLXIV, p. 41) Mr. Lloyd-Davies described a method of separating storm water by means of a side weir and a deflecting plate. Fig. 103

Section

Plan

Cross Section
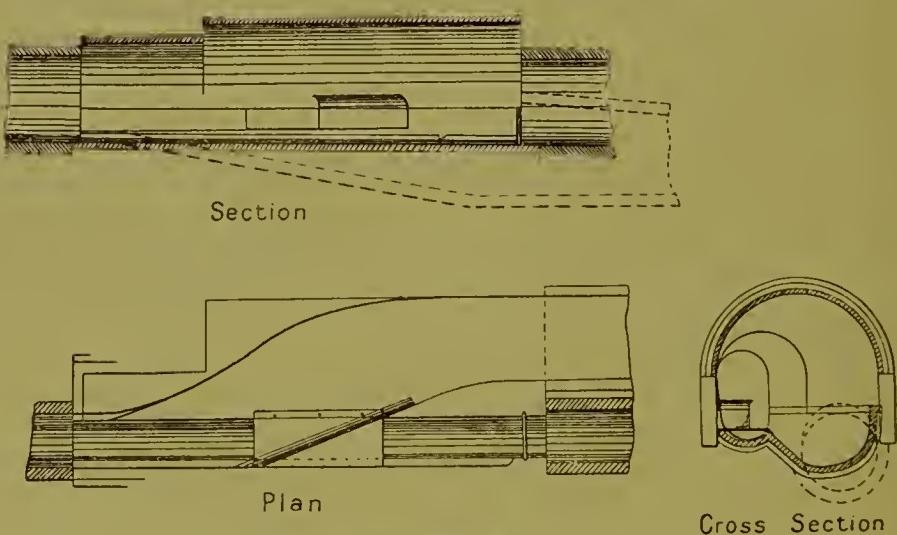
FIG. 103.—Storm Overflow, Deflecting Plate.

is copied (by permission of Mr. Lloyd-Davies and of the Institution) from a plate illustrating that paper. The deflecting plate consists of a flat plate parallel to the water surface in the sewer, set at such a level that the normal flow, or the increased

quantity which is to be retained in the sewer system, just reaches it. Any increased flow beyond this quantity results in some of the liquid passing over the top of the plate, where it is deflected by a diagonal rib and thrown over the side. The arrangement is very efficient, there being, on the other hand, the disadvantage that the deflecting plate may collect obstructive matters.

Leaping Weir.—This arrangement, designed by Mr. Baldwin Latham, was at one time very popular, but is largely superseded by the methods above mentioned. It consisted of a gap in the sewer floor, through which when the flow was small the sewage fell and was conveyed by a lower channel to the works. When the flow was too large the velocity of flow was such that the sewage leaped the gap and continued in the upper channel (Fig. 104). This gave no adjustment of quantity, and it had the further disadvantage that the

FIG. 104.—Storm Overflow, Leaping Weir.

normal sewage had to fall to a lower level. In many places the head thus lost would be of vital importance.

Separation at Sewage Works.—Assuming that six times the dry weather flow has been conveyed to the works, and that three times only are to be treated, then a further separation becomes necessary. The deflecting plate is in such circumstances (for small works at least) the most convenient. The objection which may be taken to its introduction into a sewer—that it may cause obstruction—is of less importance here, as the arrangement is in the open and any obstruction will be at once seen : or in any event would only alter the division for the time being.

CONNECTIONS TO HOUSE DRAINS

THE house drain might be regarded as terminating at the sewer, in which case the connection between the two is merely a branch on the sewer. It is very often regarded as terminating at the intercepting trap (if such exists) while the Local Government Board Committee on Intercepting Traps regard it as terminating at "the curtilage of the house." Looked at in either of these ways there is a section which is neither part of the sewer nor of the house drain, but which is called the "sewer connection" (the phrase adopted by that Committee) or the "drain connection."

Assuming that there is such a gap between the sewer and the house drain, and adopting the term "sewer connection" to describe the work required to bridge it over, that work may be said to consist of two parts—the branch on the sewer, and the connecting pipe.

Branches on Pipe Sewers.—As a branch on a pipe sewer, especially when the sewer is a small one, is large in proportion to the sewer itself, it is very important that every care should be taken that the branch is so arranged as not to interfere with the sewer flow.

The case of inserted branches will be considered later : the following deals with branches provided as part of the original construction.

The ordinary "branch pipe" has a branch socket made in one piece with the pipe, and this may be "square"—that is, the branch joins the main at right angles—as in Fig. 105, "angled" as in Fig. 106, or "curved" as in Fig. 107. For such a purpose the square is quite unsuitable, as any flow entering

at right angles causes a serious disturbance to the flow in the main sewer. If the gradient in the main sewer is steep, and if there is ample capacity in the pipes, it may cause nothing worse than needless splashing and fouling of the surface, accompanied possibly by the liberation of offensive gases ; but in other

FIG. 105.—Square   FIG. 106.—Angled   FIG. 107.—Curved
     Branch.   Branch.   Branch.

circumstances the interference may lead to deposit in one or both pipes, and in time of flood the discharging capacity may be seriously diminished. Square branches should only be used for such purposes as inspection shafts, distributing pipes on an irrigation system, or the like.

Of the others, the angled branch should be used where practicable, as the change of direction in the curved branch is too sudden. At the same time, it is very much better than the square, and cases often occur where it is not possible to use the angled branch for want of space.

Height of Branches.—The ordinary branch pipes are made with the axis of the branch joining the axis of the main, so that where the branch joins the main the two centres are at the same level (Fig. 108). If they are of the same diameter, then the inverts and the tops are also at the same level. If the diameters are different, then the invert of the smaller pipe is higher (and the top lower) by half the

FIG. 108.—Height of Branch.

difference of their diameters. Thus a six-inch branch joining a twelve-inch main will have its invert three inches above the invert of the sewer, at the point of junction. If, therefore, the main sewer is running nearly full, it is possible that the branch may be completely submerged. In practice this does not cause
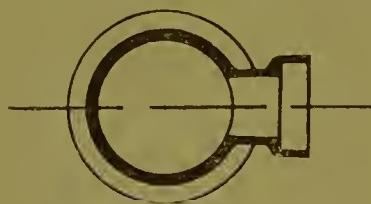
any difficulty unless the gradient of the branch is unusually flat : its gradient should be similar to that of a house drain—say, one in fifty or sixty—and it is therefore only a short distance that is water-logged. Besides, the period during which any ordinary sewer runs anything like full is very limited.

Branches on Built Sewers.—The most satisfactory connection is made by building into the sewer a proper branch block (Fig. 109) of such shape as to take the place of some of the bricks, and having a branch of suitable size and suitable angle. Failing such a branch a tolerable connection may be made by cutting the end of a pipe so as to fit the inside of the sewer and building
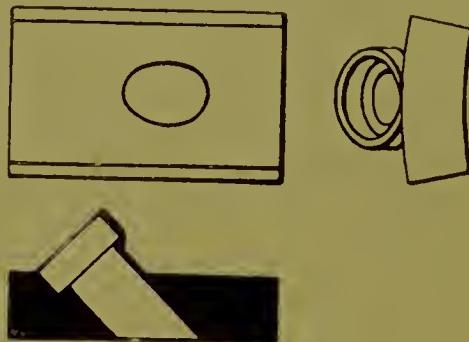
FIG. 109.—Branch Block for Built Sewer.

it carefully in with cement mortar, so that no roughness is left projecting into the sewer and no space is left round the pipe. If this is done as part of the original construction of the sewer, access can be got to all parts of the connection, and there is no reason why this should not be done in a thoroughly clean and substantial fashion. It may readily happen that a connection has to be made for which there are no suitable junction blocks at hand or readily procurable.

"**Sewer Connection,**" or the drain between the branch just discussed and the house drains, should be laid on the same principles as the house drain itself.

Where the sewer connection approaches the sewer at right angles and where an angled branch is used, the branch should be provided in such a position relative to the sewer connection

that a "slow bend" or an "eighth bend"—that is, a bend which turns through 45 degrees—can be conveniently used to join the two (Fig. 110). If a less change of direction is required the tail of the bend can be cut off to the necessary extent. It is of course better if the sewer connection can run straight into the angled branch (Fig. 111), and where the sewer and the house drainage are under construction at the same time, and when there is an intercepting trap or chamber, it is often easy to arrange this. The trap, by means of a loose head, may be used to make a bend at any angle (see *Modern Sanitary Engineering*, Part I, Figs. 22 and 24). If the distance between the sewer and the house drain is considerable, however, it is not always practicable to have the sewer connection at such an angle, as it adds substantially to its length.

Fig. 110.—Bend on Sewer Connection.

The gradient should not be less than that of the house drain, and particular care should be taken that the branch on the sewer is set to suit this gradient. In laying the pipe from the
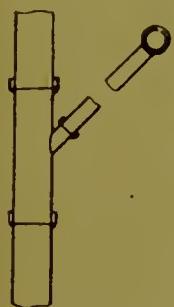
Fig. 111. Straight Sewer Connection.

branch up to the intercepting trap special care is called for in view of the fact that subsequent inspection will be much less easy than at any other part of the drainage system. In most cases indeed this section when once laid is clear of any further testing or inspection, unless some special circumstance, such as an obstruction occurring in it, should direct attention to it. It is sometimes, but not always, accessible for "rodding" by means of a "raking arm" at the intercepting trap, but this is seldom unstoppered except in the event of obstruction. The sewer connection, in fact, is apt to fall between two jurisdictions, the sewer authorities stopping at the sewer, and the sanitary authorities at the trap. There is therefore all the more reason why those who are responsible for its construction should see that it is right. When the intercepting trap joins the superannuated list, in company with many other appliances which in their day were

regarded as necessary, this short connection will no doubt be taken up definitely by the one authority or the other.

Provision for Future Connections.— When a sewer is being laid to deal with existing drains, it is comparatively easy to pick up all the branches and deal with them by means of proper branch pipes. There is, however, a considerable difficulty in providing for future connections in the case of pipe sewers. The natural method is to put in branches either with plugs clayed in, or with a cap formed in one piece with the branch, but so attached that it can be readily knocked off. The difficulty, however, is that when these branches are wanted they may not readily be found, and it is very undesirable to have a considerable part of the street torn up in the search for a branch. For this reason some authorities prefer not to provide branches for future use, but to cut the sewer and insert a branch when and where required. With built sewers, or at least those which are large enough to admit a man, the difficulty does not exist, as the position of the branch can be found from the inside, and located before the ground is opened. It is also less common to have built sewers in places where future building is expected, except in the case of large main outfalls, in which case the connections will be collected by subsidiary pipe sewers.

Inserted Junction Pieces.—If necessary it is comparatively easy to cut a brick sewer and insert a junction block, but it is still easier to insert the end of the pipe without the junction block, which is therefore often omitted. There is no reason why the result in either case, given careful work, should be unsatisfactory. With pipe sewers there is considerable difficulty in making a satisfactory insertion, and there is no method quite free from objection.

An old method, described by Baldwin Latham in his book on Sanitary Engineering, was to bare at least three pipes, and then to spring these pipes up into an arched form until the joints came apart. A plain pipe could then be taken out and a branch pipe put in its place, the whole being afterwards lowered into the original bed. This is quite inapplicable with modern cement

joints, as the pipes would inevitably be broken. It might be practicable in a modified form, the original three pipes being *broken* out, and the substituted pipes, one having the required branch, lowered into place so as to interlock the joints in the descent. Even this, however, requires the careful chipping out of the cement from the socket of the pipe which is left in the trench, and breakage of this socket is not unlikely, while it is very difficult to get the new pipes to form a straight and true gradient with those which have not been disturbed. The disturbance of the street or other surface is very considerable.

On the whole, it is probably less objectionable to cut into the existing pipe as it lies, and to insert a branch " saddle " piece,
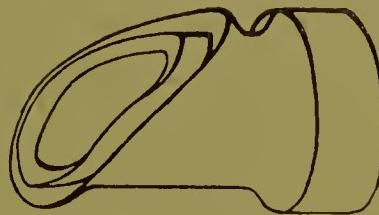
FIG. 112.—Branch Saddle Piece for Pipe.

such as is shown in Fig. 112. The branch piece has a collar shaped so as to rest on the outside of the pipe, on which it is bedded with cement mortar, while the short projecting spigot enters the cut hole. The spigot should only be long enough to reach the inside, without any projection. If the pipe is neatly cut and the joint carefully made, the result is fairly satisfactory, though by no means so good as if the branch had been provided from the first by a proper branch piece. In jointing the insertion branch to the pipe, the hand can be put in through the branch to finish the inside of the joint, and it is of the utmost importance to make sure that the finish is smooth and clean. At best, such a connection has very little strength, as it depends on the adhesion of the cement to the glazed pipe. If it has to resist any internal pressure a block of concrete should be formed right round it.

For another method, simply cutting a hole in the pipe and inserting the end of another pipe into the opening, there is nothing

to be said unless it might have to be done to meet some emer-
gency. In such a case the badness of the job may be modified
but not removed by extreme care in cutting the end of the
inserted pipe to fit the inside curvature of the main, and in
making the connection thoroughly tight with cement.

CHAPTER XVII

SEWERAGE work is for the most part carried out by local authorities, and is sometimes done by " direct labour " or " administration "—that is, the workmen are employed and the materials purchased by the local authority, and the operations supervised in every detail by the officials. In that case there is no contract, and therefore the specification for the execution of the work is purely descriptive.

On the other hand, the work may be, and more frequently is, carried out by " contract." The local authority details the work which it wants to have done, and a contractor undertakes to do it for a suitable payment. In this case the local authority has nothing to do with the execution of the work, further than supervising it to see that it is done in terms of the contract. The basis of the contract is the " Specification," in conjunction usually with a " Schedule " or " Bill of Quantities."

Two Aspects of Specifications : Descriptive and Legal.—The Specification may be regarded in the first place as simply a detailed description of the work to be done, drawn out so that those carrying out the work may see clearly and understand fully what is required. To this extent it is applicable to both direct and contract work ; but under a contract the specification assumes a new position and becomes part of a legal and binding document. It is the instrument by which either party can compel the other to carry out his obligation.

From the one point of view a general description might be sufficient. From the other, it is essential that it should stand the close scrutiny to which it might be subjected in a law-court, where every phrase and every word is examined, and

where in the event of doubt the construction *unfavourable* to the party framing the document will probably be adopted.

The last statement is not made in any sarcastic fashion : it is a mere statement of usual and quite intelligible practice. The specification is drawn up wholly by the one party, the other having no say whatever. The contract which follows it, and of which it becomes a part, is drafted by the one party, but is open to the revision of the other. Hence the completed contract represents the combined action of the two parties, while the specification is the work of one. If, therefore, the specification leaves any room for doubt it is not an unreasonable assumption that it is meant to be read in the way least onerous for the party who had no hand in preparing it. It was open to the other party to make the wording perfectly free from doubt, and it was his fault if he neglected to do so.

When ambiguity occurs in a specification it is usually because the writer of the document had so clearly in view what he meant to express that he did not see the other possible meaning, which the contractor in equal good faith may take. There is the other possibility that the contractor noticed the ambiguity, and made a mental note to carry out the more profitable of two alternatives unless he got special orders to do the other, in which case he would insist that it was beyond his contract and formed an " extra." It is an important part of the engineer's business to see that such ambiguities are eliminated before the specification is issued.

Sir Alexander Kennedy, in his Presidential Address to the Institution of Civil Engineers (*Proceedings*, Vol. CLXVII), deals briefly but clearly with the matter of specifications, concluding as follows : " Strictness, or even what is called severity, in a specification is not in itself against the interest of the contractor. As long as he can see what is wanted it is his business to prepare for it. If the contractor presumes on the engineer being slack in construing his requirements, that is his fault, and he is rightly penalised when it turns out that he has caught a tartar. But a carelessly worded specification, or one in which important requirements are slurred over or only indicated inferentially, is unfair to the contractor, is unworthy of the engineer, and is

likely to lead both into trouble as well as to result in unsatisfactory work."

"**Bills of Quantities**" or "**Schedules.**"—These are frequently prepared by the engineer and issued to offerers along with the specification. But legally they are contractor's documents. They are prepared as a guide to the contractor in offering, as without them each offerer would have to prepare some sort of schedule for himself. Hence although these are prepared at the instance of the employer, they are paid for wholly or in part by the contractor, and it should be made quite clear that the employer gives no warranty of their correctness. They describe in detail the various items of work which are required, and indicate the quantity under each heading. To a great extent they become supplementary to the specification, the specification being confined to conditions and general description, while the schedule gives the detail of each individual part. It is convenient that this should be so, for in pricing the items the details are more fully under the eye of the contractor if they appear in the description of the item than if the description was merely " as specified," involving a reference to the specification and possibly a tedious search for the particular description. While therefore the specification should contain all the general descriptions—such as the required standard for cement, the composition of concrete, the quality of pipes and bricks, and the like, it may quite well be relieved of details such as the trade description of each valve, the dimensions of manhole covers, and generally the materials of which there are numerous individual sizes or descriptions not readily grouped under one general statement.

It is sometimes stated in the specification that it and the schedule are to be read as one document. They ought to be so read, each in its respective sphere, but not to the extent that one has to make good the omissions of the other. A common cause of dispute between engineer and contractor is that some requirement is specified, but that no reference is made in the schedule to this requirement. For example, a specification may say that manholes are to be built of " nine-inch brickwork

in Portland cement mortar, pointed inside," the schedule merely mentioning so many yards of nine-inch brickwork, without reference to pointing. The contractor points the inside, but claims that it is an extra, on the ground that it does not appear in the schedule. All dubiety would have been avoided had the words " including inside pointing as specified " been added to the schedule item, but without some such phrase there is much to be said for the contractor's view that this requirement was not properly brought to his notice. He was no doubt told by the specification that the brickwork was to be pointed, but he might quite reasonably expect when he was pricing the brick-work that he would find an item for pointing, unless he was expressly told that the main item covered the other. The printed description of any schedule item should make it perfectly clear that the price is to cover subsidiary items, if that is actually the intention.

"**Slump (or Lump) Sum** " or "**Measurement** " **Offers.**—The employer may elect to ask offers on either of these bases. In the one case the contractor examines the plans and specification, aided by whatever schedule may have been drawn up, and then offers to execute the work for a fixed or " slump " or " lump " sum. He takes the risk of finding that the work is more extensive than he had expected, as against the chance of finding that he gets it done more easily. The employer knows how much he will have to pay, unless he chooses to order alterations. In the other case the schedule gives the approximate quantities as estimated, but it is stipulated that the work will be measured on completion and paid for as actually executed. Such a schedule may contain hundreds of items, and any one of these may turn out to be under or over the actual figure.

Each system has its own advantages. The " slump " system fixes the price (apart from alterations) once for all, and no further measurement of the work is required. To the employer this is a very substantial advantage. On the other hand, the contractor takes a greater risk, and naturally puts in a higher price : and there is also a much greater probability of dispute

owing to the real or alleged inaccuracy of the information furnished to the contractor, and to real or alleged extra work necessitated by circumstances impossible to foresee. The schedule for such an offer should be drawn out with most minute accuracy.

The " after-measurement " system does not give the employer a definite figure as the cost of the work; but it allows the contractor to price his offer at rates which are really fair prices for each individual part, without any margin by way of insurance against error, as he knows that any error in the quantities originally scheduled will be corrected when the after measurement comes to be made. The engineer in scheduling work on this basis may judiciously inflate some of the quantities as against possible omissions.

While there are some classes of work in which the slump system has on balance the advantage, there is little doubt that for sewerage work that is not the case. The nature of the work does not lend itself to any accurate scheduling, and changes in position, depth, etc., of sewers are often necessitated by information which is only obtained (and only obtainable) after the work has started. It is frequently found necessary to alter a line of sewers, and the nature of the strata does not always agree with the forecast. It is quite impossible, even by boring up to the furthest practicable limit, to form any accurate estimate of the amount of rock cutting that will be needed, and a contractor who has to estimate on an indefinite quantity like this will very properly put on a substantial margin for contingencies. All round it may be said that the slump system means that the contractor takes the risk of contingencies, and provides against that by adding to his price; in the measurement system the employer takes the risk and gains or loses as the case may be. In work where contingencies are so uncertain as in this it is better for the employer to take the risk.

PRECAUTIONS IN SCHEDULING

Altered Quantities.—In a schedule for after measurement it is specified that the actual quantity will be paid for at the

schedule rates. This is not necessarily fair, and contractors try to set a limit to the increase or deduction—especially if they find that an item at a not very remunerative rate is largely increased, or a remunerative item is largely reduced. A frequent contention is that 10 per cent increase or diminution is reasonable, but that if that is exceeded then the work should be valued on the basis of "*quantum meruit*," which legal phrase practically means that the contract should be cancelled to the extent necessary to let that part of the work be priced at a remunerative rate. Engineers are not disposed to admit this contention, but they would readily admit on the other hand that there are cases where special allowances are necessary. If, for example, a quantity of concrete requiring timbering were priced by the cube yard, and if by reducing the thickness the number of cube yards was seriously reduced without an equivalent reduction in the timber work, then the price per cube yard might be very unfair. Again, if a certain class of work were scheduled in quantities which justified the introduction of special plant—say steam pumping as an ordinary instance—and if that were cut down to a trifle which could have been much more economically carried out by ordinary appliances, the change may cause a very decided loss to the contractor.

"**Loss of Profit.**"—This may be a serious cause of contention. A contractor takes a job in which there is a large quantity of work which he reckons can be done at a substantial profit, and in pricing other items he does so very cheaply, relying on the profitable item to keep him right on the whole. If this should be dropped or largely curtailed, his profit disappears, and he may then claim for "loss of profit" owing to the removal of the profitable work. The extreme case is when the employer finds it necessary to abandon the whole work after the contract has been fixed. This can only be done (*a*) by consent of both parties ; or (*b*) by the party who breaks the contract satisfying the claims of the other for breach of contract. Failing the first method of settlement, which would of course include an amicable settlement of claims, these claims would be dealt with either by arbitration or in a law-court.

Provisional Items.—Any quantities which either from their nature or from the circumstances of the case are subject to special uncertainty should be indicated as such, and this serves as a warning to the contractor that he must deal with these strictly on their own merits and price them on their own cost. It is not, however, wise to ask for prices without quantities being given, unless the option of using them or not lies entirely with the employer. For example, it is quite safe to schedule two alternatives, noting that only one is to be extended into the cash columns, if they represent a choice between two rival materials —say, cast iron as against steel tubes for some section of sewer. Such an alternative usually means that either is regarded as suitable, and that the price will be the determining factor. The contractor in such a case has no reason for pricing either of them at other than fair rates. It should be made quite clear that the choice lies with the engineer, and if a fancy price is put on the one it merely means that the other is chosen. But if the choice is determined by facts yet to be ascertained, and which leave no option, then the case is very different. Rock cutting is the most conspicuous example of this : the work must go through whether it is altogether through soft material or through solid rock.

Suppose it is put in this way, which is perhaps not very uncommon : " State price per cube yard for rock cutting if required." A contractor sees at once that the price he enters will have no effect on his total, and if he has reason to expect that rock in considerable quantity will be encountered, he may speculate on this probability by putting in a very large price for rock, and applying part of his prospective gain to lowering the prices which actually do tell on his total, and thereby increasing his chance of getting the work by being (apparently) the lowest offerer.

Suppose, on the other hand, that a provisional quantity for rock is scheduled, the quantity being such that any large rate will make a substantial difference on the total : the contractor cannot go very far in the way of excessive pricing without throwing himself out. If his local knowledge is sufficient to let him know that no rock will be encountered he may speculate in

the opposite direction, by putting in trifling prices for rock and adding more or less to the other items; but this can only be done within narrow limits, and the result can scarcely be very great.

One further possibility is that in such a case a claim may be made for the *absence* of rock. It might be said for example that the schedule spoke of so many cube yards of rock, which was counted on for making concrete or for road bottoming, and that the non-existence of the rock not only deprived the contractor of the expected profit from its excavation, but forced him to import material in place of it.

The general conclusion to be drawn is that items which are provisional should be clearly described as such, so as to convey a distinct warning to the contractor that he may or may not have to deal with them.

GENERAL CONDITIONS IN SPECIFICATION

For ordinary sewerage work, the following are the chief points that the engineer will have in view in drawing out his specification.

General Description of Work.—This will give in a few lines the general nature of the work—the construction of a main sewer or of main sewers, of various branch sewers, of manholes, flushing tanks, etc., alterations on existing sewers and making connections between the old and the new, connecting house drains, etc.—mentioning specially any of the features which are not necessarily to be inferred from what is already mentioned.

Drawings.—Reference may be made to the drawings, of which a list, or merely a statement of the number, may be given, noting also that further drawings may be furnished during the course of the work, and that all drawings, specifications, etc., are to be returned to the engineer on the completion of the work.

Power to Alter.—This should always be specifically reserved, and it is well to stipulate that the express written order of the

engineer is required, and that such alterations, additions, or omissions shall in no way affect the contract.

Quantities. It must be clearly stated whether the work is to be measured on completion or whether the offer is to be for a lump sum. If it is to be measured, it should be stated by whom the measurement will be done, and this naturally will be the same person or firm who took out the original quantities. There is no reason against the engineer acting in this capacity, and it is very common that he does so ; but, on the other hand, if quantity surveyors accustomed to that class of work are available, there is no reason against their employment.

Rates.—It should be made clear that the whole work is to be covered by the items given in the quantities, unless in the case of added work. Local customs vary, and in one locality it may be customary to measure separately subsidiary items which in another locality would be included in the main items. A contract of substantial size will attract offerers from different localities. It should also be made clear that the rates are to cover everything in the nature of tools, plant, and supervision.

Increase in Costs.—Before the war, the contractor took the risk of any increase in cost of material, or rise in wages. The former risk he usually passed on, by completing contracts for supplies as soon as he had secured the contract for the work. It is now customary to throw these risks on the employer. The following is an example of such a stipulation attached to an offer : " This offer is made subject to a compensating increase in amount should any additional cost to us ensue during the progress of the work entailing (*a*) extra allowance or advance of wages to workmen by war bonus or otherwise, or (*b*) advance in cost or in carriage of materials, including delay in transit, and *vice versa* a compensating decrease in amount." Under present conditions it is impossible to say that such a stipulation is unreasonable, but it makes the ultimate cost of any work, however carefully estimated, a very uncertain quantity.

Time Work.—This is always unsatisfactory to the engineer, and it may, on the other hand, be much more remunerative to the contractor than measured work. There may thus be a constant effort on the one hand to avoid it and on the other to introduce it. It can seldom be avoided altogether, and the specification should stipulate its limitations, of which the chief is that if the contractor is of opinion that certain work cannot be measured and must be paid for as time work he must intimate this before commencing the work, so that the time may be properly vouched by the representative of the engineer. He should further be called on to submit detailed statements of such work at regular short intervals, so that these may be compared with the inspector's notes. Of course this procedure only applies to work which does not appear in the schedule : if it does so appear it must be measured and paid for at schedule rates : but a contractor may contend that a certain piece of work, while apparently a schedule item, is in reality so different that schedule rates do not fairly apply, and that it should be paid for by time and material.

Maintenance.—The obligation to maintain for a given time (usually twelve months after the date of completion as certified by the engineer) should be specially mentioned ; but it should also be mentioned that this in no way interferes with the power of the local authority to make use of the work. In sewerage work the use begins while the work is in progress if branch drains or house connections have to be picked up as it goes on. It is well to reserve power to the local authority to make any urgent repairs, or any which the contractor may neglect, at the cost of the contractor.

Payment.—The terms of payment should be clearly stated. The contractor necessarily sinks a substantial amount of capital in the work, and the method of payment should be so adjusted that this is not unduly onerous while it is sufficient to make it to his financial interest to see the work through. It is usual to provide for payments at intervals depending on the nature and extent of the work. Where the work is of large size and goes

steadily on, monthly payments are convenient, and the contractor may be called on to submit each month a statement of work which he claims to have done during the preceding month. This statement is either made up by measuring along with the engineer's representative, or is checked by him ; and on being satisfied of its correctness, or on being otherwise satisfied that a payment is due, the engineer issues to the contractor a certificate. It is often stipulated that no certificate will be issued for less than a stated amount, that amount being what should fairly be earned during the period between two payments in view of the size of the job and the time allowed for its completion. It is usual to pay either 85 or 90 per cent of the amount actually earned, but not to pay it to the exact amount so calculated. The certificate in ordinary cases would be for a round figure in the immediate neighbourhood of the actual sum, and it is well to specify that the issue of a certificate does not imply the accuracy of any claim which may have been made or the satisfactory execution of any part of the work.

Retention Money.—The 10 or 15 per cent not paid as above forms the " Retention Money " which is a security that the work will be satisfactorily carried through and maintained. It gradually becomes greater, and the security thus given is in the early stages of the contract very small (see p. 191). The contractor is deprived of the use of his money for a considerable time, as the retention money is not paid up as a rule till the expiry of the period of maintenance. It is fair, therefore, that interest should be paid on this, and the usual stipulation is that a certain interest (generally 4 or 5 per cent before the war) will be paid on the amount retained, counting either from the date of each certificate, or from the date of completion, until final payment. The terms should be clearly stated in the specification.

Accident, Damages, etc.—It should be expressly stated that the contractor is liable for any accident of any description, and must meet any claim for damages at the instance either of his own men or of the general public. In view of the somewhat far-reaching liability which attaches to employers it may be well to

bind the contractor to produce a satisfactory policy of insurance covering such risks, or to stipulate that a policy is to be taken in the joint names of employer and contractor. It is well to put a schedule item for insurances.

Fencing, etc.—The contractor should be called on to put up any temporary fencing that may be required, and to do all watching and lighting. It is well to provide a schedule item to cover these requirements.

Occupation of Ground.—Whether the operations are in public streets or in private property it must be made clear to what extent the contractor is entitled to occupy the ground. In the case of a narrow street it may be necessary to suspend traffic entirely, and in a wider one it may be greatly hampered : the contractor in either case should know clearly either what may be done, or to whose instructions he is to work as regards time of closing, length of street to be opened at a time, and so on. In private ground the specification should indicate the conditions of working, means of access, width of ground which may be occupied, and should make it clear that any responsibility for trespass will rest on the contractor.

Temporary Buildings.—Accommodation of various kinds is needed for tools, stores, material such as cement which must be protected from the weather, and for office work. It may be necessary to provide lodging and sanitary accommodation for the men employed. To a certain extent the contractor is the judge of what is needed, but in some respects he must meet the requirements of the engineer—the storage of cement for example, while in others, such as accommodation for men, the sanitary authorities have requirements which must be met. The specification should make it clear to what extent the contractor is to meet all these temporary obligations. He is usually called on to provide office accommodation for the representative of the engineer, and all attendance, fuel, light, etc. A telephone connection may sometimes be needed.

Progress and Completion.—It is often specified that the work must be completed within a certain period from the acceptance of offer "under a penalty of" so many pounds sterling per week for any time required after the date so fixed. This clause is of little value, and is scarcely enforceable. A variation of it is to say that a certain sum per week will be deducted for delay, "this sum being in the name of agreed-on damages and not as a penalty." This is better, but still of doubtful value. If it is of urgent importance to have the work finished as soon as possible it is easy to make the bargain legally enforceable by letting it cut both ways : say that if the work is finished before the stated time a premium of so much per week or per day will be paid, while if it is not finished the same sum per week or per day will be deducted for delay. If such a bargain came into court, it would probably be held that there was a fair bargain, and that the parties had agreed on a money value for the time. The time allowed should be a reasonable one ; and if it is merely the intention to prevent unreasonable delay, the contractor in offering may be asked to say what time he will take under the condition of addition or deduction just stated. It may sometimes pay the contractor, and at the same time be a great convenience to the employer, to have the work pressed on in the way that such a stipulation encourages. In practice, unless the contractor has been actually dilatory, it is usual to read such a clause in a fairly liberal spirit, and it is wise to reserve power to the engineer to extend the time in the event of unforeseen circumstances, such as unusually bad weather. Failing such reservation, the local authority might make very unreasonable demands. A further stipulation ought to be made that in the event of persistent delay the employer shall have power to take over and complete the work, and to use all the contractor's plant and material, at the risk and cost of the contractor, and without liability for depreciation or loss, on giving, say, three days' written notice.

Provision for Bankruptcy.—It should be stipulated that in the event of the bankruptcy or insolvency of the contractor the employer may take over the work, withholding any further

payment until the sum finally due is definitely ascertained. In working for a private individual the contractor might find it necessary to have some corresponding protection inserted in the contract ; but a local authority acting under its statutory powers is not likely to be unable to meet its obligations.

Description of Materials, Workmanship, etc.—The minor details may appear merely in the schedule, but the general description of quality should be clearly specified. This may imply a considerable amount of descriptive writing, in which specific words should as far as possible be used instead of vague ones.

Supervision.—The contractor should always be present in person or represented by a man not only competent but with sufficient authority to act at once on any orders given by the engineer, and this should be specially stipulated.

Arbitration Clause.—It is usual to have a clause referring any disputes to a named " Arbitrator " or " Arbiter " (the former term is used in England, the latter in Scotland). Some engineers put in their own names, which is not satisfactory. The contractor does not like it, and the engineer is put in a needlessly awkward position. Throughout the work he has to act in a judicial capacity, deciding from time to time points as to construction in which he is practically a judge as between the employer and the contractor, but if any points should arise in which his rough-and-ready and purely informal decision is not accepted it is desirable that the formal decision should lie with someone else. The engineer has almost inevitably committed himself to a certain opinion, and it is difficult to avoid at least the suggestion of bias, although possibly his conscientious scruples may turn the bias in favour of the contractor. Sir Alexander Kennedy in the Presidential Address above quoted (see p. 178) expresses " strong views as to the inadvisability of making an engineer the arbitrator in relation to his own specification." Arbitration is in no case very desirable, and it is not always preferable to litigation. The named arbiter is usually

an engineer of standing, but a man may be a successful engineer and be entirely lacking in the judicial mind necessary in a satisfactory arbiter.

Extraordinary Traffic on Roads.—This is becoming a more and more troublesome question. The responsibility for settling any claims is usually thrown on the contractor, and contractors regard this as unreasonable. If the roads are the property of the employer, it will usually be possible to make an estimate of the damage which will be done, and either say that the responsibility will not be thrown on the contractor, or that it will be met by certain charges, subject in either case to certain conditions being observed. If the roads belong to an outside authority, it might be possible to reach an agreement with them before issuing the specification, although that is not always practicable. There is a good deal to be said both for and against the prevailing practice.

Contract, Security, etc.—The specification forms the basis of the contract, in conjunction with the contractor's offer. For trifling work the contract never gets further than an exchange of letters, which when stamped become binding, but for work of more importance it is customary to have a contract drawn up in legal form and fully executed. That is a matter for the law advisers on both sides, but the specification should include an obligation to enter into a formal contract. The question of security has already been mentioned in connection with retention money, but it will be seen from the preceding paragraphs that there are numerous responsibilities thrown on (and accepted by) the contractor, which failing him would fall on the employer. It is therefore necessary to see that the employer has sufficient security not only for the execution of the work, but for the discharge of these responsibilities.

Such security is given in various ways. The contractor may find personal " Sureties " who will sign a bond of security for him. He may produce a policy of insurance covering the same obligation. He may deposit a sum of money at first, quite apart from the retention money. He may allow the retention money

to be deducted at first at a greater rate than 10 or 15 per cent, so that the total will be in the hands of the employer before the work has advanced far. On the whole the insurance policy is in the majority of cases the most satisfactory. It may be that the standing of the contractor is sufficiently good and sufficiently well known to make special security unnecessary.

CHAPTER XVIII

THE DRAINAGE AND SEWERAGE OF HOUSING SCHEMES

THE conditions under which housing schemes are carried through have introduced several special problems in connection with sewerage and drainage, and it may be useful to consider the application to these special problems of the principles which have already been discussed.

Ownership of Houses.—The housing scheme may be carried out by the Local Authority, by a company or society, or by private enterprise ; and the intention may either be to retain the proprietorship as a whole or to dispose of the houses to individuals. Some of the difficulties do not arise so long as the houses remain altogether in the possession of the Local Authority, and others only arise when the ownership is divided among a large number of individuals.

Responsibility for Sewer Services.—The question has been raised repeatedly as to whether the sewerage and other " communal " services should be provided as part of the housing scheme or whether such provision is part of the ordinary duty of the Local Authority. The latter is the usual decision, and it simply means that the cost is to be defrayed by the Local Authority as in the case of an ordinary sewerage scheme, the necessary funds being obtained by rating.

Advantages of a Housing Scheme as compared with Single Buildings.—There is the great advantage that a substantial number of houses are designed as a group and not promiscuously, and that therefore the sewerage can be planned in advance,

and not merely arranged to suit houses which have been already constructed, often in the most awkward places. There is a further advantage in respect of the economy of carrying out work on a large scale, and in many cases the advantage of supervision of a kind not likely to be available for single small houses.

Difficulties.—The drainage difficulties are the natural result of the improved conditions which are demanded, emphasised by the need for rigid economy. It is (economically) an easy matter to provide sewers for a population which is housed in tenements or flats : it is a much more serious undertaking when the same population is spread out at the rate of fifty or sixty to the acre. When houses are built in uniform rows fronting long and straight streets there is no great difficulty in having reasonable lengths of straight sewer ; but when for artistic or other reasons the lines are broken and irregular, such lengths of straight sewer are apt to involve branches of such a length as to add materially to the cost, and sometimes to introduce difficulties with regard to gradient. Again, the sanitary accommodation is naturally at the back of the houses, and the street sewers are in front ; and while this difficulty is by no means confined to housing schemes, and is one indeed which may be more easily dealt with in such schemes than in detached building, the scale on which it is encountered makes it more impressive.

Pipes through Private Ground.—This point has been discussed in Chapter I (p. 13), and it was there indicated that the special conditions of housing schemes might overrule the conclusion that would be reached on general principles. There are various reasons for this.

In private building operations the plots may be given off in an absolutely haphazard fashion, or according to a more or less carefully arranged building plan, but each plot is conveyed (sold, leased, or in Scotland " feued ") to an individual holder, who as a rule has no power to make any use of the adjoining plot. He therefore has to take the drainage of his building direct to the public sewer, the whole route being on his own or on public ground. This of course is to some extent modified in the

case of a builder taking off ground for several houses ; but speaking generally the ordinary builder is dealing with an individual plot while the designer of a housing scheme may be dealing with hundreds. The latter has therefore a much freer hand, and naturally uses it to secure every possible economy.

There is an undoubted economy in grouping the drainage of a number of houses, and the financial conditions of housing schemes make it important that this economy should be realized. When such schemes are carried out by the Local Authorities, and so long as the whole property remains in its hands, the drawbacks are not very serious. Difficulties occur even if the whole property is in one ownership, unless that owner is the Local Authority ; and these may be very marked when the various houses become the property of individuals.

Sewers or Drains.—The ideal arrangement, from the point of view of the Local Authority, would be that no channels should be classed as sewers until they had emerged from the private property on to the public road or street. The usual legal definition is that a channel serving more than one house is a sewer, but this definition seems to serve chiefly as a peg on which to hang litigation. There are certainly some exceptions. A flatted house may contain a number of dwellings, but the main drainage channel is a drain and not a sewer. It has on occasion been agreed between the parties concerned that the drainage system of each block of houses, the block containing a number of houses side by side, was a drain and not a sewer. In the case of housing schemes carried out by others than the Local Authority, arrangements have been made under which the latter undertook responsibility for the sewage only after it had been brought to the public roads, and this would seem to be where practicable a desirable limit.

Lanes.—The difficulty of taking the drainage from the backs of houses, and at the same time of keeping sewers clear of private ground, is sometimes met by the provision of lanes. These are never desirable—two well-known authorities on town planning, discussing the matter with the author, agreed that lanes were " a physical and a moral nuisance "—and they are less needed

in housing schemes than under any other conditions. It is desirable to have an access to the back other than through the house, and when houses are built in long continuous rows this can only be given by a lane ; but when the houses are detached or in small groups access to the back is readily arranged between them. In the one case a lane is needed for other purposes and may be a convenient route for a sewer ; in the other case it is undesirable to form a lane merely as a sewer route.

Disadvantages of Grouped Drainage.—If the houses are owned separately, grouped drainage implies that some of them (probably most of them) are subject to a " servitude," " easement," or " wayleave " in favour of their neighbours. An owner may wish to make some alteration or improvement, and find that he cannot do so because it would interfere with his neighbour's drainage ; or he may find (perhaps after serious mischief has been done) that a drainage channel of whose existence he was unaware is choked or leaking. Even under the old conditions when grouped drainage only resulted from the fact that a builder had drained his own block of houses after that fashion, the author has seen numerous cases where great trouble has arisen in this way. It is quite fair to assume that the drains of the present day will require reconstruction in the future, just as the drains of the past require reconstruction now.

Apart from all questions of ownership, a drain or sewer in private ground is exposed to risks from which a street sewer is free. No one may disturb the surface of a public road without a permit from the responsible authority, but any man may dig in his own garden, and in so doing he may readily smash a pipe. He may or may not realize its importance ; even if he does there is no certainty that he will do otherwise than fill up the hole he has made in the ground, leaving the pipe to look after itself. The result is a leak or a choke, which may only be located and remedied with difficulty and expense, and the value of disturbed garden produce may be a substantial addition to the latter.

The use of the appliances may be more careless because of the drainage being other than individual, just as it is found

that closets used in common by more than one household are almost inevitably in worse order than those which serve only one.

Design of Grouped Drainage.—Assuming that in spite of these drawbacks the advantages of grouping are sufficient to warrant its adoption, the following points of design should be kept in view :

Size.—The channels are intermediate between sewers, whose usual minimum diameter is 9 inches, and house drains, whose usual diameter is 4 inches. For the smallest groups 4 inches is probably enough, but it will frequently be desirable also to use 5-inch and 6-inch pipes. Nothing larger than 6-inch is likely to be needed. In the largest groups the connection from the sewer will probably be 6 inches, and the pipe might be reduced to 5 inches when it received the drainage of perhaps ten or twelve houses, and to 4 inches when it received only about four. At the points where the main becomes smaller diminishing pipes or " reducers " should be used, while the branch connections should be made by branch pipes of proper size, of which the pipe manufacturers provide an ample choice. Bends and junctions should all be made at proper angles, as described on p. 171.

Gradient.—The gradients should as far as possible be those which would be suitable for house drains of the same diameter. The greater flow in these group drains, as compared with the drains of an ordinary house, might in the case of the largest pipes justify a slightly less fall. For example, a 6-inch drain of this type might be laid at a gradient which in ordinary house drainage would only be justified by the use of special flushing appliances ; but any such relaxation of ordinary rules is trifling, and must be considered very critically before it is sanctioned. The subject is fully discussed in *Modern Sanitary Engineering*, Part I.

It is inevitable that these comparatively small pipes, even the largest of them, must have more fall than would be given to a sewer, and if the site is at all flat it is essential to concentrate the flow into the sewer as early as possible. The principle is exactly the same as is discussed on p. 11 with reference to outfall

sewers, and its application will show that while a long drain, serving various groups of houses, may be economical so far as actual pipe length is concerned, its effect on the necessary depth of sewers may be serious. Unless the site has a considerable natural fall, it is necessary, in order to avoid excessive depth, to keep these small pipes short. The sewer, which carries the concentrated flow of a number of these drains, may of course be laid at a flatter gradient.

Access Openings.—These should be provided very freely. The housing standard is being raised, and in some cases the rise is sudden. One result is that houses fitted with modern appliances are sometimes occupied by people who have been accustomed to very rough-and-ready equipment, and who use the closets as receptacles for all sorts of rubbish. Instances of extraordinary misuse are already on record. Among the obstructions which have come to the knowledge of the author, in connection with the drainage of new housing schemes, are included about half a pail of potatoes, the greater part of a sheep's skull, and bulky articles of clothing. Time and experience will effect an improvement, but it will always be useful, and in the meantime it is urgent, to make very full provision for access.

It is not always necessary to have built manholes. Inspection eyes on the pipes are usually sufficient, and if the depth is not great it may not be necessary to extend them to the surface. They may be finished as indicated in Fig. 38 of Part I of *Modern Sanitary Engineering*, and an indication of their position given on the surface or on an adjoining wall. An alternative is to use access pipes of the " Tron " or " Armstrong " type, where the pipe has a round or square opening of considerable size which may be extended to the surface by an extension piece. This does not give much room if " rodding " should be necessary, but it ensures that the opening will be readily found, and it is better than the simpler plan of merely extending a round pipe like a lamphole (Fig. 83) to the surface.

Trapping.—The omission of intercepting traps gives great scope for economy. Fig. 113 shows one section of the Glengarnock Housing Scheme (indicated by a cross on the general plan of the same scheme shown in Fig. 114), the upper part
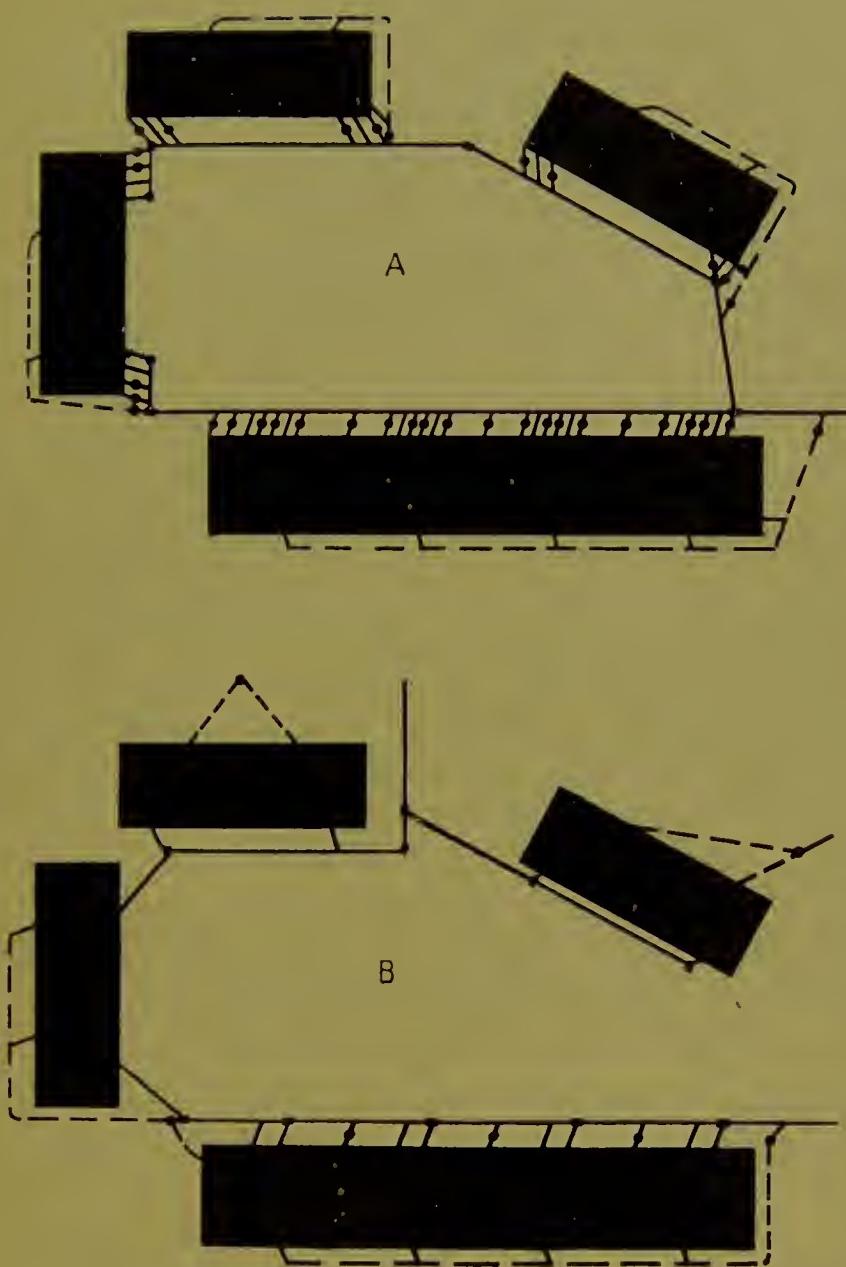
FIG. 113.—Part of Glengarnock Housing Scheme.
    A. With traps as usually required.
    B. As carried out without traps except for rain water
        connections.
    Dotted lines indicate rain water drains.
    Round spots indicate traps.
    Rectangular spots indicate inspection openings.

showing the drainage system with the usual complement of
traps, and the lower part showing the system as actually carried
out, without any intercepting traps except for rainwater pipes
and drains. The greater simplicity and consequent economy
are obvious, and as the connections between the different dis-
charge pipes—from closets, baths, etc.—are made above ground
there is (as a rule, for there are a few exceptions to suit the
planning of the houses) only one connection to the drain from
each house.

A reference to the general plan will show also that if the usual
method of trapping had been adopted, and if consequently the
usual number of branches had been needed, the main drains
could not have been kept so far from the houses except at a
serious cost. The closer proximity of the main drains to the
houses would not only have been undesirable in itself, but it
would have involved a much more tortuous route.

It is not of course suggested that the plan actually adopted is
above criticism. It is merely given as an example of how the
principles discussed in the text (and not always, as in the case of
joint drains through private ground, with approval) were applied
to the one particular case. Some desirable features had to be
abandoned, and some less desirable features had to be adopted,
to meet special circumstances, but no one concerned with the
work has any doubt that the experience has fully justified the
abandonment of the usual system of interception. An extension
of the scheme on similar lines is at present in progress.

Heavy lines indicate sewers.
Lighter lines ,, drains.
Dotted lines ,, rain-water drains.
Solid spots ,, manholes and inspection openings.
Open spots ,, traps.

Scale of Feet
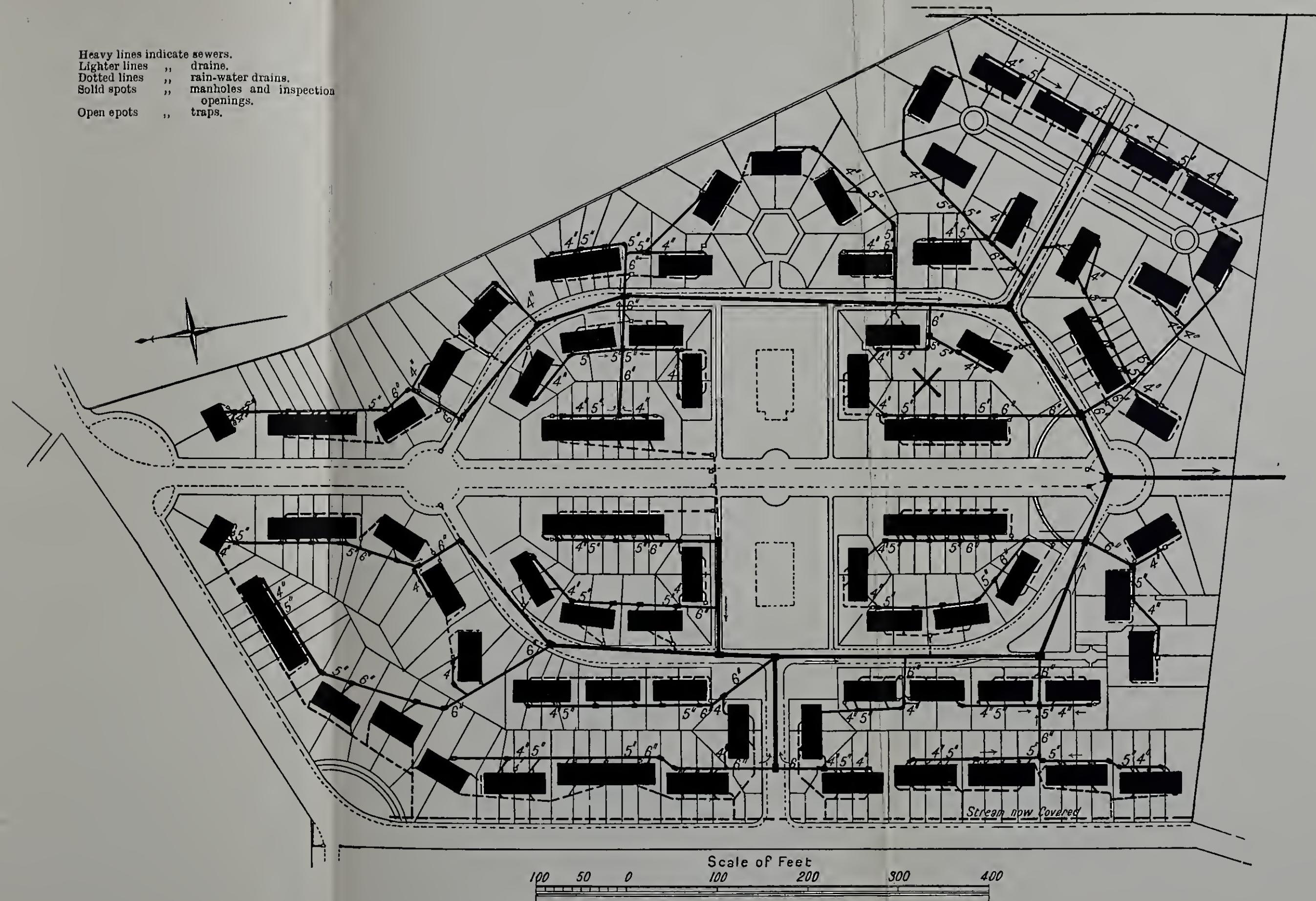
Fig. 114.—Glengarnock Housing Scheme, Sewers and Drains.
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